U.S. DEPARTMENT OF COMMERCE

PB80-174220

Computer-Aided Synthesis of Wastewater Treatment and Sludge Disposal Systems

(U.S.) Municipal Environmental Research Lab.
Cincinnati, OH

Dec 79

U.S. Department of Commerce
National Technical Information Service
NTIS

United States
Environmental Protection
Agency

Municipal Environmental Research
Laboratory
Cincinnati OH 45268

EPA-600/2-79-158
December 1979

PB80-174220

Research and Development

EPA

Computer-Aided Synthesis of Wastewater Treatment and Sludge Disposal Systems

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-79-158	2.	3. RECIPIENT'S ACCESSION NO. PB80 174220
4. TITLE AND SUBTITLE COMPUTER-AIDED SYNTHESIS OF WASTEWATER TREATMENT AND SLUDGE DISPOSAL SYSTEMS		5. REPORT DATE December 1979 (Issuing Date) 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Lewis A. Rossman		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Municipal Environmental Research Laboratory--Cin., OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268		10. PROGRAM ELEMENT NO. 1BC821, SOS 1 11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Same as above		13. TYPE OF REPORT AND PERIOD COVERED Inhouse (Feb. - Oct. 1978) 14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES

Project Officer: Lewis A. Rossman 513/684-7636

16. ABSTRACT

A computer-aided design procedure for the preliminary synthesis of wastewater treatment and sludge disposal systems is developed. It selects the components in the wastewater treatment and sludge disposal trains from a list of candidate process units with fixed design characteristics so that criteria on effluent quality, cost, energy, land utilization, and subjective undesireability are best satisfied. The computational procedure uses implicit enumeration coupled with a heuristic penalty method that accounts for the impact of return sidestreams from sludge processing. The programmed version of the design procedure, called EXEC/OP, has been interfaced with the unit process subroutines contained in a previously EPA developed system evaluation program known as EXECUTIVE. A number of case study design problems are presented to demonstrate the versatility of EXEC/OP. Included among these is a preliminary cost/energy-effectiveness analysis for a hypothetical design problem containing over 15,000 alternative system configurations.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Waste treatment Sludge disposal Facilities Systems analysis Optimization	Waste water treatment Waste treatment facilities Sludge treatment Treatment facilities System synthesis Multi-objective planning	13B

18. DISTRIBUTION STATEMENT Release to public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

☆ U.S. GOVERNMENT PRINTING OFFICE 1980 -657-146/5556

EPA-600/2-79-158
December 1979

COMPUTER-AIDED SYNTHESIS OF WASTEWATER TREATMENT AND SLUDGE DISPOSAL SYSTEMS

by

Lewis A. Rossman
Wastewater Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

i.a

DISCLAIMER

This report has been reviewed by the Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

The work presented here describes the development and use of a computer-aided preliminary design procedure for wastewater treatment and sludge disposal systems. It enables a designer to efficiently synthesize and analyze large numbers of alternative treatment schemes and rank them with respect to several different cost, energy, and environmental criteria. Such a design tool should enhance our capability to develop more innovative and efficient waste treatment systems in these times of stricter environmental standards and increasing resource costs.

Francis T. Mayo
Director, Municipal Environmental
Research Laboratory

ABSTRACT

A computer-aided design procedure for the preliminary synthesis of wastewater treatment and sludge disposal systems is developed. It selects the components in the wastewater treatment and sludge disposal trains from a list of candidate process units with fixed design characteristics so that criteria on effluent quality, cost, energy, land utilization, and subjective undesireability are best satisfied. The computational procedure uses implicit enumeration coupled with a heuristic penalty method that accounts for the impact of return sidestreams from sludge processing. The programmed version of the design procedure, called EXEC/OP, has been interfaced with the unit process subroutines contained in a previously EPA developed system evaluation program known as EXECUTIVE. A number of case study design problems are presented to demonstrate the versatility of EXEC/OP. Included among these is a preliminary cost/energy-effectiveness analysis for a hypothetical design problem containing over 15,000 alternative system configurations. The design approach described in this report will be of interest to engineers and planners involved in the generation and evaluation of alternative wastewater treatment and sludge disposal systems.

This report covers a period from February 1978 to October 1978 and work was completed as of February 1979.

CONTENTS

Foreword iii
Abstract iv
Figures vi
Tables vii

1. Introduction 1
2. Conclusions 3
3. Elements of the System Design Process 4
4. An Overview of the System Synthesis Model 10
5. Case Studies 19

References 50

Appendices

A. Mathematical Description of the Model 53
   References 60
B. EXEC/OP Users' Guide 61
C. Unit Process Descriptions 86
   References 100
D. Program Listing 102

FIGURES

Number		Page
1	Conceptual Flow Diagram of a Waste Treatment System	10
2	Multi-Option Flow Diagram for a Hypothetical Design Problem	15
3	Multi-Option Flow Diagram for Case Study 1	22
4	Multi-Option Flow Diagram for Case Study 2	28
5	Multi-Option Flow Diagram for Case Study 3	36
6	EXEC/OP Output for Case Study 4	38
7	Illustration of the Non-Inferior Set	45
A1	Flow Chart of the Implicit Enumeration Procedure	56
A2	Overall System Design Algorithm	59
B1	Multi-Option Flow Diagram for a Hypothetical Design Problem	62
B2	Organization of Input Data for EXEC/OP	64
B3	Input Data for Hypothetical Design Problem	68
B4	EXEC/OP Output for Hypothetical Design Problem	71
B5	EXEC/OP Output for Single Design Evaluation	78

TABLES

Number		Page
1	Evaluation Criteria for The LA/OMA Sludge Management Study	6
2	Assessment of Waste Treatment System Optimization Models	8
3	Unit Processes Contained in EXEC/OP	12
4	Waste Stream Parameters in EXEC/OP	13
5	Influent Waste Characteristics Used for Case Studies	20
6	Economic Parameters Used for Case Studies	21
7	Input Process Design Parameters for Case Study 1	23
8	Input Design Parameters for Vacuum Filtration and Centrifugation	25
9	Least-Cost Designs for Case Study 1	26
10	Input Process Design Parameters for Case Study 2	30
11	Least-Cost Designs for Case Study 2	32
12	Input Process Design Parameters for Case Study 3	34
13	Least-Cost Design for Case Study 3	36
14	Least-Cost Energy Constrained Design for Case Study 5	47
15	Non-Inferior Cost/Energy Systems for Case Study 5	48
B1	EXEC/OP Unit Processes	63
B2	EXEC/OP Design Criteria	64
B3	EXEC/OP Waste Stream Parameters	65
B4	EXEC/OP Economic Parameters	66

SECTION 1

INTRODUCTION

The effective synthesis of waste treatment systems is a challenging engineering task. The term synthesis refers to the specification of both a system structure - the choice and arrangement of unit processes and operations - and the design of the individual units within that structure so that a set of design objectives is fulfilled. Although the primary goal may be the treatment of liquid wastes, decisions regarding sludge handling and disposal can have significant impacts on total system performance, in both an economic and environmental sense.

In the preliminary phases of the system design process the designer needs to efficiently evaluate the performance of a large number of potential system designs to identify a smaller number of attractive designs that will then become the subject of a more detailed and accurate evaluation. This screening process can become complicated for a number of reasons. First there is the rapid geometric growth in the number of alternative system designs possible as more unit processes and design levels are taken into consideration. Second, the evaluation of each system design should consider the effect that liquid sidestreams generated from sludge treatment have when recycled back to the wastewater treatment portion of the system. The feedback effect of these recycles complicates the numerical calculation of system performance. In many instances these two factors can combine to make a complete evaluation of all possible system designs computationally intractable. If only intuition were used to select a more manageable number of designs to examine, one could never be sure that some truly attractive alternative was not overlooked.

A third reason for the complexity of the screening process is reflected in the multi-objective nature of the design problem. For example, the least-cost waste treatment scheme need not be the most preferred. Other criteria related to such considerations as energy consumption, reliability, resource recovery, and public acceptance can have a significant role in the decision making process. The 1977 Clean Water Act (P.L. 95-217) [1] recognizes this fact by allowing trade-offs to be made among factors such as these for treatment systems eligible for federal construction grants. Thus the preliminary screening process should also be capable of generating alternative system designs that show the kinds of trade-offs that may exist between various design criteria.

This report describes a computerized system synthesis model, called EXEC/OP, that can aid the designer in the preliminary stages of the system design process. The model can be thought of as an optimization version of a previously EPA developed treatment system evaluation program known as EXECUTIVE [2]. From a specified list of unit process options with fixed design or performance characteristics the model selects the combination of units that will best meet a set of system design criteria. These criteria include cost, energy consumption, land utilization, a subjective undesireability rating and effluent discharge limits. EXEC/OP also has the capability of identifying the M system designs that are within X% of the best. It avoids having to evaluate the performance of each possible system configuration by employing an implicit enumeration search technique coupled with a heuristic penalty function method used to account for the effects of recycled sidestreams from sludge processing.

The following sections of this report discuss the various features of the model and present a number of sample design problems that illustrate its versatility. The appendices contain a mathematical development of the model and a Users' Guide and program listing of EXEC/OP.

SECTION 2

CONCLUSIONS

The EXEC/OP computer program for synthesizing waste treatment systems provides a useful tool for the preliminary screening of alternative designs. Its features include an integrated design of both the wastewater and sludge treatment sub-systems, consideration of multiple components in the waste streams, selection of both the type and design level for unit processes, and consideration of multiple design criteria. The penalty augmented implicit enumeration method employed in its optimization algorithm is an efficient means of searching for the best combinations of process options. Usually only a small fraction of the computational effort that would have been required for complete enumeration of all possible alternatives is needed.

The program gives the designer a useful means for exploring trade-offs between such criteria as cost, energy consumption, land utilization, and subjective undesireability ratings. These factors can be weighted and combined into a single criterion function or can be treated as constraints placed on the system design. Additional flexibility is provided by the M next-best design feature of EXEC/OP. This can be used to identify a group of designs that are close together with respect to one primary objective (e.g. cost) but could have varying levels of other secondary objectives.

The case studies described in this report show that the program is capable of analyzing design problems with from 15,000 to 21,000 alternative system configurations in several minutes of computer processor time. The core storage requirements of the program are modest at 25 K words. The subroutines that model the performance of the treatment processes have been employed in a modular fashion so that improvements and new types of unit processes may be easily added at a later time.

SECTION 3

ELEMENTS OF THE SYSTEM DESIGN PROCESS

As with most engineering problems, the design of wastewater treatment and sludge disposal systems involves the elements of synthesis, analysis, and evaluation [3]. The element of synthesis refers to the conception of a system structure and its operating characteristics. Analysis determines how a given system structure will behave under specific design and operating conditions. The evaluation step compares the performance of alternative system designs so that a best design may be identified.

The entire design process consists of a linking together of these three elements in an iterative fashion. Information feedback from the analysis and evaluation phases is used to suggest changes to be made in the synthesis step. Any new designs so generated are then analyzed and evaluated as the process cycles through another iteration. Also, the level of detail and accuracy maintained in the analysis will usually increase as the process proceeds. In the preliminary stages, levels just high enough to perform an efficient yet reliable screening of a very large number of alternative system designs is all that is required.

There are two types of decisions to be made when synthesizing a waste treatment system. The first type involves the system structure - a choice of the kinds of treatment processes to employ and the arrangement of these units with one another in the system. Examples of such structural choices would be whether to use activated sludge or a trickling filter for BOD removal, whether to employ a single treatment train for sludge processing or separate trains for different types of sludges, and whether to use land spreading of liquid sludge or landfill a dewatered sludge. The second type of decision relates to the design of each individual unit process and operation. It specifies the values of those parameters that describe the size, operating characteristics, and performance of each unit. Examples might be the choice of an overflow rate for a settling tank, the value of the solids retention time to use in an activated sludge unit, or the choice between 10 cu. yd. and 15 cu. yd. size trucks for hauling sludge.

The identification of a best overall system design requires a search over the space of feasible structural configurations and over the space of design options associated with the individual treatment units in each configuration. The fact that the treatment units are interconnected to one another makes the performance of any one unit in the system dependent on the design decisions made for all other units in the system. Thus, for example, the best design of an activated sludge unit cannot be assured without knowing the performance achieved in primary sedimentation and, because of the recycled sidestreams, the design choices in the sludge processing train.

The evaluation of a system design must be made with respect to a set of decision criteria. The criteria that seem most relevant to waste treatment systems can usually be grouped into the categories of economics, environmental effects, performance, and feasibility of implementation. Table 1 lists the evaluation criteria that were used in the recent LA/OMA sludge management study for Los Angeles and Orange Counties in California [4]. The U.S. Congress, in the Clean Water Act of 1977, has set forth several goals that could serve as the basis for design criteria. The act provides monetary incentives for communities to employ treatment technology that will result in (a) greater recycling and reuse of water, nutrients, and natural resources; (b) increased energy conservation, reuse, and recycling; (c) improved cost-effectiveness in meeting specific water quality goals; (d) improved toxics management [1].

Criteria such as described above may be expressed in the form of a performance objective to be minimized or maximized, as constraint relations with fixed target levels, or as fuzzy combinations of objectives and constraints (e.g., design a system that has some resource conservation in it but is not too costly). Alternative designs that do not meet the constraint target levels can be discarded as infeasible. Of the remaining designs, if one ranks better in each objective than all other designs then this is clearly the best choice. What is more likely to occur though is that one design performs better than another with respect to one objective but is inferior with regard to a second objective.

For example, the treatment system that minimizes cost would probably not be the system that also minimizes energy consumption. In such cases the objectives are said to be conflicting and a final choice cannot be made without the designer imposing a subjective value judgment on the relative worth of one objective versus another. For the cost-energy situation, the designer would be faced with the question, "how much increase in cost am I willing to accept as I move from the most cost-effective system to the most energy-effective system?". Engineering analysis can only inform the designer of what trade-offs exist among the objectives in the alternative designs available. It cannot answer questions involving value judgments and thus cannot serve as the means for automatically reaching a final design decision.

The traditional approach to waste treatment system design has been to divide the system into its various component stages (e.g., primary treatment, secondary treatment, sludge stabilization, sludge dewatering, and final sludge disposal), define performance objectives for each stage, and select the treatment units that best accomplish these objectives. The result can be an uncoordinated and wasteful overall system design. More systematic approaches have recognized the interaction between various treatment components and have used mathematical models programmed for computer implementation to evaluate the overall performance of alternative system designs. The pioneering effort in this area was made by Smith and his

TABLE 1. EVALUATION CRITERIA FOR THE LA/OMA SLUDGE MANAGEMENT STUDY

- Direct Cost
  - Capital Costs
  - Operation and Maintenance Costs
  - Revenues
- Indirect Costs
  - Employment Generation
  - Induced Land Value Changes
  - Alterations in Economic Productivity
- Energy Impacts
  - Direct Energy Demands
  - Indirect Energy Demands
- Environmental Impacts
  - Public Health Hazards
  - Land Form Alteration
  - Soil Contamination, Conditioning, Reclamation
  - Water Quality
  - Air Quality
  - Ecosystem Impacts
  - Resource Utilization
  - Social Resources
  - Growth Inducement
  - Safety
  - Control of Hazardous Substances
  - Transportation System Impact
- System Effectiveness
  - Implementability
  - Flexibility with Time
  - Reliability
  - Compatibility with Existing Land Use
  - Compatibility with Related Planning Programs
  - Compatibility with Legal Requirements

co-workers at the U.S. Environmental Protection Agency [5]. This work has culminated in the development of EXECUTIVE, a computer program that simulates the steady state performance and evaluates the cost of a number of wastewater and sludge treatment unit processes that can be arranged into any reasonable system configuration [2]. Additional simulation programs devoted primarily to wastewater treatment systems have been reported on by Silveston [6], Chen, et. al. [7], and Shoemaker and Barkley [8]. Similar works devoted mainly to sludge management include those of Bennet, et. al. [9], Kos, et. al. [10], Smith and Eilers [11], Burley and Bayley [12], and the San Francisco Bay Region [13].

All of the above approaches are evaluative in nature - they rely on the designer to first specify the system design in advance. For a large number of alternative designs the computational burden can become excessive if each alternative must be synthesized and analyzed separately. To overcome this limitation, a number of mathematical optimization models have been developed for waste treatment systems in recent years. With varying degrees of generality and sophistication these models will select values for the system design variables that will meet effluent discharge standards at least total cost.

Table 2 compares a number of these models with respect to several features thought to be of particular value in the preliminary phases of the system design process. These features can be summarized as follows:

(1) The design of the wastewater and sludge treatment sub-systems should be done in an integrated fashion, with consideration given to the treatment requirements of the sidestreams produced during sludge processing;

(2) The model should select both a system structure and the design of the individual process units within that structure, at least from among a finite number of discrete alternatives;

(3) The capability should exist to handle multiple pollutants or waste stream parameters and their interactions;

(4) Whenever possible, principles of mass balance and reaction kinetics should be employed in predicting process performance and resource utilization;

(5) A capability to consider other kinds of system evaluation criteria besides cost should be included;

(6) A solution method more computationally efficient than complete enumeration of all possible system designs should be used.

None of the models in Table 2 contains all six features. It is possible to discern two types of modeling approaches in these past efforts. The first, representative of the dynamic programming models, can only synthesize the wastewater treatment sub-system with respect to one or two pollutants

TABLE 2. ASSESSMENT OF WASTE TREATMENT SYSTEM OPTIMIZATION MODELS

Authors	Integrates Wastewater and Sludge Treatment	Determines System Structure	Includes Multiple Pollutants	Uses Mass Balance and Process Kinetics Models	Includes Multiple Design Criteria	Optimization Technique	Comments
Lynn, et al. (1962) [14]	No	Yes	No	No	No	Linear Programming	Pioneering application of optimization techniques
Evenson, et al. (1969) [15]	No	Yes	No	No	No	Dynamic Programming	Uses a fixed unit cost to account for sludge disposal
Shih & Krishnan (1969) [16] and Shih & DeFilippi (1970) [17]	No	Yes	No	No	No	Dynamic Programming	
Ecker & McNamara (1971) [18]	No	Yes	No	No	No	Geometric Programming	
Berthouex and Polkowski (1970) [19]	Yes	No	Yes	Yes	Yes	Nonlinear Programming	Considers variance in BOD removal as a second design criterion
Mishra, et al. (1973) [20]	No	Yes	Yes	Yes	No	Nonlinear Programming	Optimizes recycle arrangements and parallel treatment schemes
CIRIA (1973) [21] Bowden, et al. (1976) [22]	Yes	No	Yes	Yes	No	Nonlinear Programming	Considers recycle of sidestreams from sludge treatment
U. S. Army Corps of Engrs. (1976) [23]	Yes	Yes	Yes	Yes	No	Complete Enumeration	Does not consider recycle of sidestreams
Patterson (1976) [24]	No	Yes	No	No	No	Dynamic Programming	Refinement of earlier dynamic programming model
Dick & Simmons (1976) [25]	Yes	No	Yes	Yes	No	Nonlinear Programming	Employs more fundamental process models than CIRIA model

using simple process performance relations. The second is representative of the various nonlinear programming models. It requires that the system structure first be specified in advance and then proceeds to optimize the integrated design of the individual units within that structure. It is capable of dealing with a complex system structure, multiple pollutants and realistic process performance models. Although a recent paper by Adams and Panagiotokapoulos [26] addresses many of these same concerns and suggests an approach for dealing with them, detailed computational results are only presented for a relatively simple design problem previously considered by Shih and Krishnan [16].

The decision model described in this report, EXEC/OP, has been designed to include the six features listed above. In addition, it is capable of identifying the M system designs that are within X% of the best design, where M and X are specified by the designer. This feature is especially useful in sensitivity analysis. In multi-criteria studies, it can identify system designs that are close to one another with regard to one criterion (e.g., cost) but could have varying levels of other criteria (e.g., energy consumption, land utilization). The emphasis has been placed on developing a useful design tool, capable of generating attractive alternatives that could warrant more critical evaluation, rather than producing an automated procedure for arriving at an optimal design.

SECTION 4

AN OVERVIEW OF THE SYSTEM SYNTHESIS MODEL

This section provides a description of the various conventions and assumptions employed in the system synthesis model EXEC/OP. It also discusses the initial steps needed to organize any given design problem into a suitable form for EXEC/OP. Detailed instructions on the use of the program can be found in Appendix B.

EXEC/OP views a waste treatment system as consisting of three treatment trains - one for wastewater, one for secondary sludge, and one for primary or mixed primary and secondary sludge. Figure 1 shows how these trains are connected to one another. Note how the liquid sidestreams off of the sludge treatment trains are recycled back to the wastewater treatment train. The mixing of secondary sludge with primary sludge is shown with a dashed line to indicate that the exact point of mixing will depend on the choice of treatment units in the secondary sludge train.

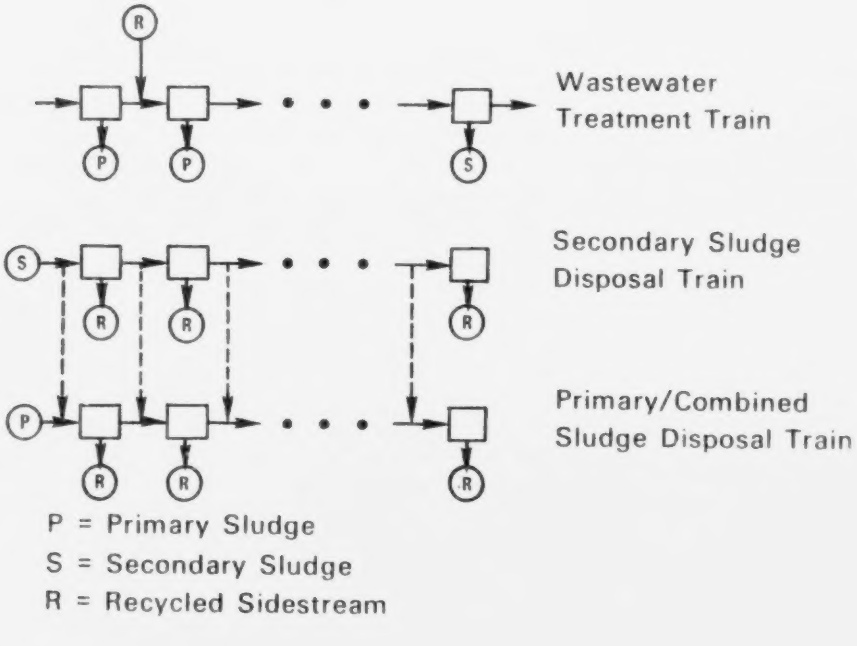

R
Wastewater
Treatment Train
P
P
S
S
Secondary Sludge
Disposal Train
R
R
R
P
Primary/Combined
Sludge Disposal Train
R
R
R
P = Primary Sludge
S = Secondary Sludge
R = Recycled Sidestream

Figure 1. Conceptual flow diagram of a waste treatment system

The building blocks of each treatment train are referred to as treatment stages. For each stage the designer indicates the various unit process options that are available for selection. These units can be different types of treatment processes or operations (e.g., activated sludge versus trickling filter), or different design levels of the same process (e.g., activated sludge with mixed liquor volatile solids concentration of 2000, 2500, or 3000 mg/l). Table 3 lists the types of unit processes and operations that are currently available to EXEC/OP. Each of these has a performance model, in the form of an EXEC/OP subroutine, that will compute effluent quality, sidestream quality, equipment size, and resource utilization (cost, energy, land) as a function of the influent waste quality and a set of process design parameters. Most of these subroutines have been taken from the EPA EXECUTIVE program [2]. Appendix C lists the design parameters associated with each process, indicates which additional design information is computed by the process model, and cites references for the technical details of the models.

It is important to understand that the design level or performance of each process option is fixed in advance by the analyst by assigning values to these input design parameters. Thus, for example, if EXEC/OP should choose gravity thickening over air flotation thickening at some sludge treatment stage, it does so on the basis of the solids loading rate and thickened solids concentration that was assumed for each type of thickener. Of course the designer is free to employ several gravity and/or flotation thickener options, each with different performance levels, to help refine the selection.

Within each treatment train only a serial arrangement of processing stages is possible. Parallel treatment units or recycling of waste streams among the units of the same treatment train is not allowed. Thus a group of process units that normally operates with a recycle flow, such as the aeration basin and final settler of the activated sludge process, is treated as a single unit with its own performance model and EXEC/OP subroutine. Added flexibility for creating alternative configurations of units is provided by means of the "null process" unit. This simply indicates that the choice of no processing at a given stage is also a possibility. Examples illustrating the use of the null process alternative are shown in the various sample design problems considered throughout this report.

Each treatment stage has an influent waste stream entering it, an effluent stream leaving it for the next stage, and, in most cases, a sidestream generated from the processing activity. For wastewater treatment stages these sidestreams would be sludge streams while for sludge treatment stages they may be filtrates, supernatants, etc. Each sludge stream is assigned to either the primary or secondary sludge treatment trains for processing. Of course eventual mixing of these streams is possible depending at what stage secondary sludge treatment ends. All sidestreams from sludge treatment are sent to a designated stage in the wastewater treatment train.

The contents of each wastewater and sludge stream are modeled with the parameters listed in Table 4. In addition to these, each sludge stream is

TABLE 3. UNIT PROCESSES CONTAINED IN EXEC/OP

Wastewater Treatment	Sludge Treatment
Raw Wastewater Pumping	Gravity Thickening
Preliminary Treatment	Air Flotation Thickening
Primary Sedimentation	Anaerobic Digestion
Aeration and Final Settler (Activated Sludge)	Aerobic Digestion
	Nonoxidative Heat Treatment
Primary Sedimentation, Aeration, Final Settler with waste activated sludge returned to the primary settler	Elutriation
	Sand Drying Beds
Trickling Filter	Vacuum Filtration
Rotating Biological Contactor	Centrifugation
Chlorination	Multiple Hearth Incineration
	Truck Transport/Land Spreading
	Truck Transport/Landfilling
	Sludge Holding Tanks

TABLE 4. WASTE STREAM PARAMETERS IN EXEC/OP

Q	Volumetric Flow, mgd
SOC	Suspended Organic Carbon, mg/l
SNBC	Suspended Nonbiodegradable Carbon, mg/l
SON	Suspended Organic Nitrogen, mg/l
SOP	Suspended Organic Phosphorus, mg/l
SFM	Suspended Fixed Matter, mg/l
SBOD	Suspended 5-Day BOD, mg/l
VSS	Volatile Suspended Solids, mg/l
TSS	Total Suspended Solids, mg/l
DOC	Dissolved Organic Carbon, mg/l
DNBC	Dissolved Nonbiodegradable Carbon, mg/l
DN	Dissolved Nitrogen, mg/l
DP	Dissolved Phosphorus, mg/l
DFM	Dissolved Fixed Matter, mg/l
ALK	Alkalinity, mg/l
DBOD	Dissolved 5-Day BOD, mg/l
NH3	Ammonia Nitrogen, mg/l
NO3	Nitrate Nitrogen, mg/l

characterized as to its origin (primary, secondary, or mixed primary and secondary) and the type of stabilization it receives (no stabilization, lime stabilization, digestion, digestion plus elutriation, and heat treatment). This feature allows many of the sludge treatment processes to be assigned different design parameter values depending on the type of sludge handled.

In summary, the preliminary steps needed to organize a design problem into a format acceptable to EXEC/OP are as follows:

(1) Determine the number of treatment stages to employ in the wastewater and sludge treatment trains;

(2) Decide on what process options and design parameter values to use at each treatment stage;

(3) Assign each sludge sidestream generated from wastewater treatment to either the primary or secondary sludge treatment train;

(4) Determine to which wastewater treatment stage the sidestreams from sludge treatment should be recycled.

In practice it will probably be necessary to perform steps 1 and 2 simultaneously to insure that the desired options are considered in the proper order.

Figure 2 illustrates what may be the result of applying these preparatory steps to a hypothetical design problem. Noteworthy features of this example as as follows:

(1) Several design options for the same process are included at stages 3, 4, 9, and 12;

(2) Sludge from primary sedimentation is sent to the primary sludge train while sludge from the activated sludge unit is sent to the secondary sludge train;

(3) The null process option is used in several places to increase the number of possible system configurations;

(4) The mixing point for secondary and primary sludges will depend on at what stage secondary sludge treatment ends. E.g., if the null process is chosen by EXEC/OP at stages 6 and 7, mixing occurs at stage 8. If the null process is chosen at stage 7 but not at stage 6, then stage 9 becomes the mixing point;

(5) The sidestreams generated from sludge processing are returned to stage 3.

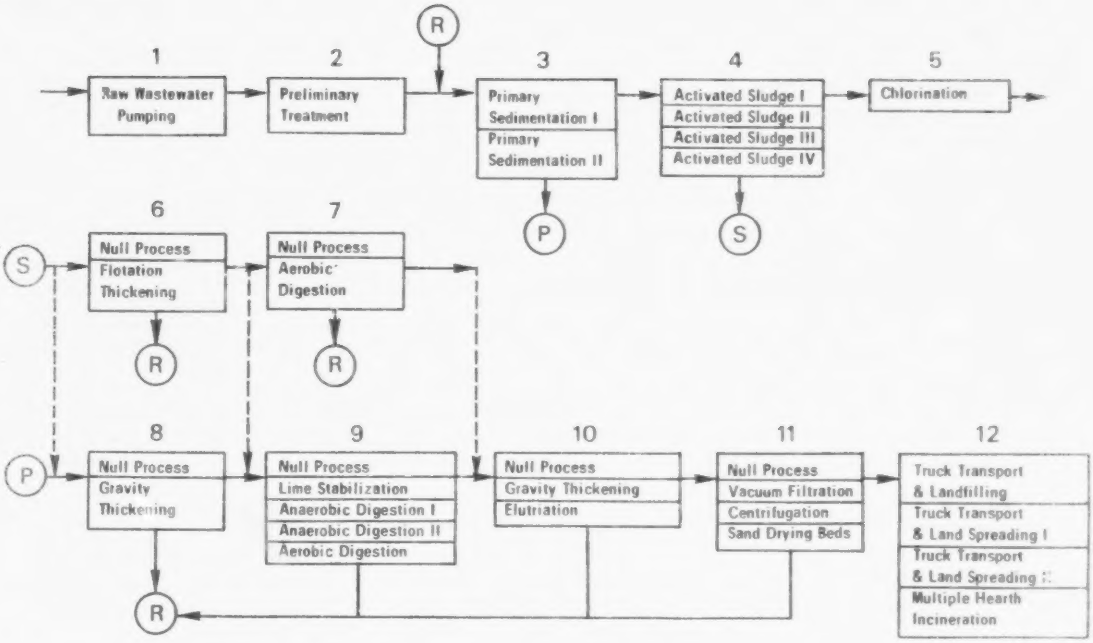

1
Raw Wastewater Pumping
2
Preliminary Treatment
R
3
Primary Sedimentation I
Primary Sedimentation II
4
Activated Sludge I
Activated Sludge II
Activated Sludge III
Activated Sludge IV
5
Chlorination
P
S
6
S
Null Process
Flotation Thickening
R
7
Null Process
Aerobic Digestion
R
8
P
Null Process
Gravity Thickening
R
9
Null Process
Lime Stabilization
Anaerobic Digestion I
Anaerobic Digestion II
Aerobic Digestion
10
Null Process
Gravity Thickening
Elutriation
11
Null Process
Vacuum Filtration
Centrifugation
Sand Drying Beds
12
Truck Transport & Landfilling
Truck Transport & Land Spreading I
Truck Transport & Land Spreading II
Multiple Hearth Incineration

Figure 2. Multi-option flow diagram for a hypothetical design problem

Once a multi-option flow diagram such as Figure 2 has been established, EXEC/OP can be used to select the process option at each stage of the system that will best meet a particular set of design criteria. The current version of EXEC/OP contains eight criteria. They are as follows:

(1) Initial construction cost (million dollars);

(2) Annual operation and maintenance costs, including all energy costs (dollars/million gallons of flow treated);

(3) Total equivalent annual cost consisting of amortized capital costs plus annual operation and maintenance costs (dollars/million gallons of flow treated);

(4) Gross energy consumption consisting of the direct electrical energy needed to operate equipment, the kwh equivalent of all fuel consumed, and the kwh equivalent of the energy used in chemical production (kwh/million gallons of flow treated);

(5) Gross energy production as the kwh equivalent of the usable energy contained in treatment by-products such as digester gas and incinerator exhaust gas (kwh/million gallons of flow treated);

(6) Net energy consumption which is the difference between criteria 4 and 5 (kwh/million gallons of flow treated);

(7) Total land utilization, excluding those process units with small land requirements (acres);

(8) Subjective system undesireability rating.

The first seven criteria should be self-explanatory. The system undesireability rating is arrived at in the following way. Each process option is given a rating by the designer on some convenient scale, say 0 to 10. The higher this rating, the more undesireable the process from whatever standpoint the designer wishes to view it. For example, anaerobic digestion may be rated as 10 and truck transport/land application of sludge be rated at 3 on the basis of reliability. If public acceptance were the issue, these scores might be reversed. Scoring systems can also be devised that take into account several forms of undesireable effects. The total system score is simply the sum of the unit process scores for those options selected in the system design. This is an admittedly crude attempt to incorporate qualitative factors into the screening process. Obviously the designer should use this feature with considerable caution to insure that treatment options are being compared on an equitable and acceptable basis.

The heating value of all fuels is converted into an equivalent electrical energy rating by using an assumed conversion efficiency figure. This figure reflects the thermodynamic efficiency of converting heat energy into electrical energy. Typical values would be from 8,500 BTU/kwh (40 percent conversion efficient) to 11,300 BTU/kwh (30 percent conversion efficiency).

The criteria listed above can be combined into a weighted objective function whose value is to be minimized or can be assigned target limits and treated as constraint conditions by EXEC/OP. The objective function would have the form

$$v = w_1 c_1 + w_2 c_2 + w_3 c_3 + w_4 c_4 - w_5 c_5 + w_6 c_6 + w_7 c_7 + w_8 c_8$$

where the w_i, i=1,..., 8 are weighting coefficients chosen by the designer and the c_i, i=1,..., 8 are the individual criteria values. Note that $w_5 c_5$ is given a negative value since energy production is to be maximized. The weights should reflect the relative value that each criterion should contribute to deciding which system design is "best". For example, if reducing total cost were thought to be twice as important as reducing gross energy consumption, then the values of w_3 and w_4 should be in the ratio 2:1. For simply minimizing total cost, one would set $w_3 = 1.0$ and all other $w_i = 0$.

Another use for these weights would be to assign a cost credit to any energy produced through waste treatment. For example, if the value of such energy net of its conversion cost was $0.011/kwh and one was trying to minimize total cost then $w_3 = 1.0$ and $w_5 = 0.011$ with all other $w_i = 0$.

Note that the cost of energy consumption is accounted for in the cost criteria 2 and 3.

When the above criteria are considered as constraints, each is assigned an upper limit (or lower limit for energy production) which cannot be exceeded by any feasible system design. An additional set of constraints consists of the required effluent quality of the wastewater discharge. EXEC/OP can consider effluent standards for 5-day BOD, total suspended solids, phosphorus, ammonia nitrogen, and nitrate nitrogen. Limits on discharges of residuals to the land and air can appear as part of the design parameter data for the individual process units. For example, the process model for land application of sludge asks the designer to supply an allowable nitrogen loading rate in lb N/acre.

EXEC/OP can operate in two different modes of calculation. In the optimization mode it selects the combination of process options that will best meet the stipulated design criteria. In this mode the program can also be asked to identify the M next-best designs that are within X% of best, where M and X are chosen by the designer. The single design evaluation mode allows the user to obtain a detailed description of the performance of a particular system design. This includes the composition of all wastewater and sludge streams and the values of all computed unit process design parameters - information that is not available from the optimization mode because it would require a prodigious amount of computer output. The same input data is used for both modes except that the last lines of data for a single design evaluation lists the process option to be selected at each stage of the system.

The computational algorithm of EXEC/OP employs two basic features. The first is the replacement of the recycle stream from the sludge treatment trains by a vector of penalty terms. These penalties approximate the change in the value of each design criterion as a unit of mass flow of each component of the sidestreams from sludge treatment is returned for treatment in the wastewater treatment train. This device converts the entire treatment system into a serial one, where the waste stream entering stage i is only affected by the decisions made at stages 1, 2,..., i-1.

The second computational feature is an implicit enumeration algorithm that is used to find the optimal unit process choices for the penalty-augmented serial system. It is able to screen out large categories of possible process combinations by employing a simple bounding property. The result is that only a small fraction of the total number of system configurations need to be explicitly evaluated.

Since the values of the recycle penalties depend on the choice of unit processes in the system, an iterative procedure is employed to update the values of these penalties. After each iteration has identified a new, potentially optimal system design by implicit enumeration, the units selected for that design are used to establish new penalty values and another iteration begins. The process stops when a previously generated system design is once again arrived at. The final design is taken as the best design arrived at over all iterations. The penalty values associated with this design are then used once again in the implicit enumeration procedure to identify the M next-best designs. A more detailed, mathematical description of the complete algorithm is presented in Appendix A.

The use of recycle penalties is a heuristic device and thus there is no guarantee that EXEC/OP will be able to identify the true mathematical optimum design. However the error involved would most certainly be small since the recycle stream from sludge processing usually represents only a fraction of the total waste loading on the system. Also, the search for the M next-best designs based on penalty values may be able to identify a design that actually performs better than the best design arrived at in the optimization portion of the algorithm. An example of this is shown in one of the case studies presented in the next section. Finally, given the nature of the preliminary screening process, the designer is less interested in obtaining a mathematical optimum than in generating a set of attractive alternatives and eliminating those that are clearly inferior. EXEC/OP was developed with this type of goal in mind.

SECTION 5

CASE STUDIES

This section demonstrates the capabilities of EXEC/OP by means of several system design case studies. It should be understood that the problems analyzed are purely hypothetical. The values used for the process design parameters were specifically chosen to make several processes competitive with one another. Therefore, no general conclusions regarding the general superiority of one type of process versus another should be drawn from these examples.

The case studies to be presented were chosen to illustrate the following types of design problems:

(1) Cost minimization of a conventional secondary treatment system with the emphasis on the choice of sludge management strategies;

(2) A cost minimization of secondary treatment featuring several non-conventional arrangements of primary sedimentation and activated sludge units;

(3) Refinement of the design for Case Study 1 with the emphasis on the choice of design parameter values for a fixed arrangement of process units;

(4) A detailed performance evaluation of the design arrived at in Case Study 3;

(5) A cost/energy-effectiveness analysis for the process options considered in Case Study 1.

All of the case studies are for a 10 mgd system whose influent wastewater characteristics are given in Table 5. Values assumed for various economic parameters are shown in Table 6. All examples must provide an effluent quality of 30 mg/l of 5-day BOD and 30 mg/l of suspended solids.

CASE STUDY 1

In this example, the least cost combination of process units will be found for the multi-option flow diagram in Figure 3. In addition, the four system designs closest to least-cost will also be sought. Note that several choices of primary sedimentation and activated sludge design levels are available. Separate thickening and/or aerobic digestion of

TABLE 5. INFLUENT WASTE CHARACTERISTICS USED FOR CASE STUDIES

Component	Value
Volume flow, mgd	10. (37,850 cu m/day)
Suspended organic carbon, mg/l	105.
Suspended nonbiodegradable carbon, mg/l	30.
Suspended organic nitrogen, mg/l	10.
Suspended organic phosphorus, mg/l	2.
Suspended fixed matter, mg/l	30.
Suspended 5-day BOD, mg/l	140.
Volatile suspended solids, mg/l	224.
Total suspended solids, mg/l	254.
Dissolved organic carbon, mg/l	43.
Dissolved nonbiodegradable carbon, mg/l	11.
Dissolved nitrogen, mg/l	19.
Dissolved phosphorus, mg/l	4.
Dissolved fixed matter, mg/l	500.
Alkalinity, mg/l	250.
Dissolved 5-day BOD, mg/l	60.
Ammonia nitrogen as N, mg/l	15.
Nitrate nitrogen as N, mg/l	0.

TABLE 6. ECONOMIC PARAMETERS USED FOR CASE STUDIES

EPA Sewage Treatment Plant Cost Index	2.88 (December 1977)
Wholesale Price Index	2.00 (December 1977)
Discount Rate	0.06375
Planning Period	20 yr.
Direct Hourly Wage	5.91 $/hr.
Fraction of Direct Hourly Wage Charged to Indirect Labor Costs	0.15
Cost of Electricity	0.033 $/kwh
Cost Escalator for Yardwork, Laboratories, Legal Fees, Engineering and Interest	1.33
Efficiency of Converting Heat Value of Fuels to Equivalent Electrical Energy	0.31

waste activated sludge is also possible. Ultimate sludge disposal can be accomplished by either land spreading at one of two alternative sites, landfilling, or incineration. The process options shown in Figure 3 can be arranged into 15,360 different system configurations.

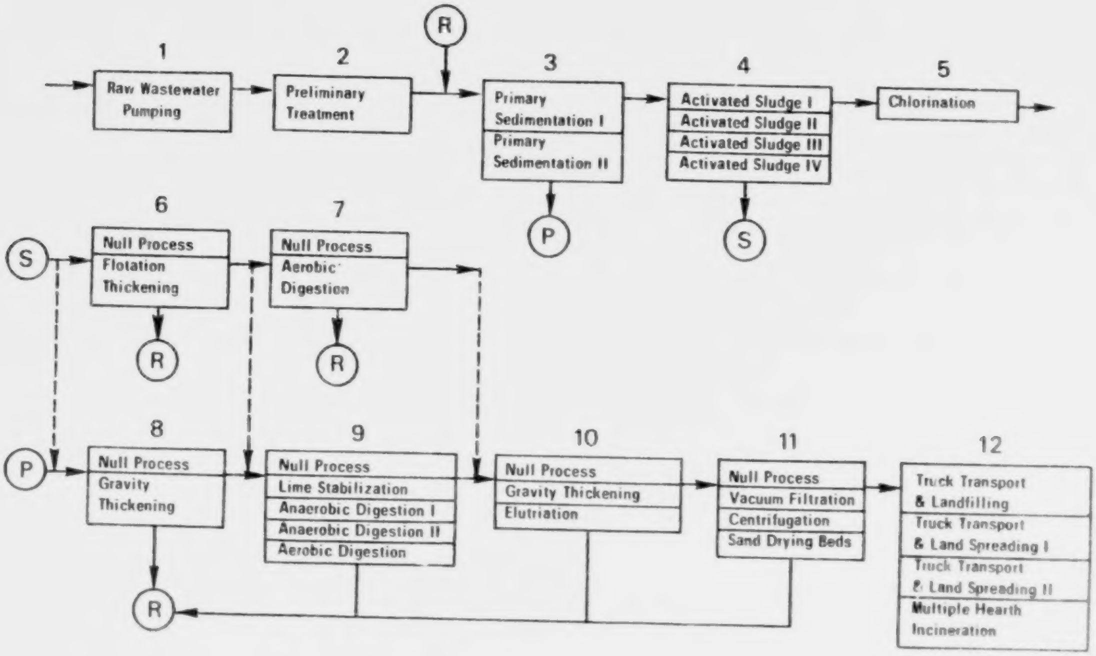

1
Raw Wastewater Pumping
2
Preliminary Treatment
R
3
Primary Sedimentation I
Primary Sedimentation II
4
Activated Sludge I
Activated Sludge II
Activated Sludge III
Activated Sludge IV
5
Chlorination
P
S
6
Null Process
Flotation Thickening
7
Null Process
Aerobic Digestion
8
Null Process
Gravity Thickening
9
Null Process
Lime Stabilization
Anaerobic Digestion I
Anaerobic Digestion II
Aerobic Digestion
10
Null Process
Gravity Thickening
Elutriation
11
Null Process
Vacuum Filtration
Centrifugation
Sand Drying Beds
12
Truck Transport & Landfilling
Truck Transport & Land Spreading I
Truck Transport & Land Spreading II
Multiple Hearth Incineration

Figure 3. Multi-option flow diagram for case study 1

Table 7 provides information on the input design parameters for the unit process options. Additional data for the vacuum filtration and centrifugation options are given in Table 8. Since this example seeks to minimize total cost, the only non-zero selection criterion weight is for criterion 3, total cost. All constraint limits on the various criteria have been set to arbitrarily high numbers (or to 0 for energy production).

The results of running this problem with EXEC/OP are shown in Table 9. The first portion of the table lists the designs arrived at for each iteration of the optimization phase of EXEC/OP. These are then followed by a listing of the 5 least-cost designs identified in the sensitivity phase of the program. These results show that three iterations were needed on the penalty terms to obtain the least-cost design. It consists of using 60 percent solids removal in primary sedimentation, activated sludge at 3000 mg/l mixed liquor volatile solids and 30 percent recycle, anaerobic digestion of mixed primary and secondary sludge for 15 days, thickening to 5 percent solids, sludge drying on sand beds, and incineration of dried sludge. The total cost is 27.6 ¢/1000 gal. The somewhat surprising result of choosing sludge incineration over land disposal may be due to the high cost of land,

TABLE 7. INPUT PROCESS DESIGN PARAMETERS FOR CASE STUDY 1

PRI = primary sludge	WAS = waste activated sludge	MIX = PRI + WAS
Process	Design Parameter	Value
Pumping	Pumping Head, Ft.	30.0
Preliminary Treatment	Grit Removal	Yes
	Flow Measurement	Yes
	Screening	Yes
Primary Sedimentation I	TSS removal, %	40.0
Primary Sedimentation II	TSS removal, %	60.0
Activated Sludge I[a]	MLVSS, mg/l	2000.0
	Recycle ratio	0.3
Activated Sludge II	MLVSS, mg/l	2000.0
	Recycle ratio	0.5
Activated Sludge III	MLVSS, mg/l	3000.0
	Recycle ratio	0.3
Activated Sludge IV	MLVSS, mg/l	3000.0
	Recycle ratio	0.5
Chlorination	Chlorine dosage, mg/l	8.0
	Contact time, min.	30.0
Air Flotation Thickening	Solids recovery ratio	0.95
	Underflow TSS, %	4.0
	Loading, lb/day/sq ft	48.0
Gravity Thickening	Solids recovery ratio	0.9
	Underflow TSS,	8.0 (PRI) 5.0 (MIX)
	Loading, lb/day/sq ft	16.0 (PRI) 8.0 (MIX)

[a] All activated sludge alternatives are also required to attain an effluent quality of 30 mg/l BOD_5 and 30 mg/l TSS.

(continued)

TABLE 7 (continued)

Process	Design Parameter	Value
Anaerobic Digestion I	Detention time, days	15.0
Anaerobic Digestion II	Detention time, days	20.0
Aerobic Digestion	Detention time, days	10.0 (WAS) 20.0 (PRI & MIX)
Lime Stabilization	Dosage, lb/ton dry solids	200.0
Elutriation	Solids recovery ratio	0.76
	Underflow TSS, %	4.0
	Loading, lb/day/sq ft	8.0
	Washwater ratio	3.0
Vacuum Filtration	Loading, gph/sq ft	10.0
	Chemical dosage, %	See Table 8
Centrifugation	Solids recovery ratio	See Table 8
	Cake solids, %	
	Feed rate, gpm	
Sand Drying Beds	Cake solids %	30.0
	Storage detention time, days	15.0
Incineration	Mass loading, lb/hr/sq ft	2.0
	Heat value of volatiles, BTU/lb	10000.0
	Type of fuel	oil
Land Spreading I	One way haul distance, miles	10.0
	Cost of land, $/acre	3000.0
	N application rate, lb/acre/yr	400.0
	Site preparation cost, $/acre	500.0
	Spreading cost, $/dry ton	10.0
Land Spreading II	One way haul distance, miles	30.0
	Cost of land, $/acre	2000.0
	N application rate, lb/acre/yr	600.0
	Site preparation cost, $/acre	500.0
	Spreading cost, $/dry ton	10.0
Landfilling	One way haul distance, miles	10.0
	Cost of land, $/acre	3000.0

TABLE 8. INPUT DESIGN PARAMETERS FOR VACUUM FILTRATION AND CENTRIFUGATION

Vacuum Filtration Chemical Requirements

Ferric Chloride, % / Lime, %

Sludge Type	Stabilization Process Used Raw	Limed	Digested	Digested/Elutriated
Primary	2.1/8/8	2.1/0	3.8/12.	3.4/0
Primary + Waste Activated	2.6/10.	2./0	5.5/18.5	6.25/0

Centrifugation Design Variables

Solids recovery ratio / Cake solids, % / Polymer dose, lb/ton / Feed rate, gpm

Sludge Type	Stabilization Process Used Raw	Limed	Digested	Digested/Elutriated
Primary	.9/32/3/90	.9/30/3/160	.9/25/2/100	.9/25/2/100
Primary & Waste Activated	.9/19/6/80	.9/30/4/160	.85/22/4/80	.95/22/4/80

TABLE 9. LEAST-COST DESIGNS FOR CASE STUDY 1

Design	Wastewater Process Selections[a]	Sludge Process Selections	Total Cost, ¢/1000 gal.	Gross Energy Consumption kwh/mil gal.	Energy Production kwh/mil gal.
Optimization Phase					
1	Primary Sedimentation II Activated Sludge III	Gravity Thickening Anaerobic Digestion I Elutriation Land Spreading I	29.1	1234	411
2	Primary Sedimentation II Activated Sludge III	Anaerobic Digestion I Gravity Thickening Sand Drying Beds Incineration	27.6	1307	419
3	Same as Design 2				
Sensitivity Phase					
1	Same as Design 2 of Optimization Phase		27.6	1307	419
2	Primary Sedimentation II Activated Sludge III	Anaerobic Digestion I Gravity Thickening Land Spreading I	27.8	1265	418

(continued)

TABLE 9 (continued)

Design	Wastewater Process Selections	Sludge Process Selections	Total Cost, ¢/1000 gal.	Gross Energy Consumption, kwh/mil gal.	Energy Production, kwh/mil gal.
3	Primary Sedimentation II Activated Sludge III	Anaerobic Digestion I Gravity Thickening Sand Drying Beds Landfilling	27.8	1225	419
4	Primary Sedimentation II Activated Sludge III	Anaerobic Digestion II Gravity Thickening Sand Drying Beds Incineration	28.0	1353	426
5	Primary Sedimentation I Activated Sludge III	Anaerobic Digestion II Gravity Thickening Sand Drying Beds Landfilling	28.1	1271	426

[a] All designs utilize Pumping, Preliminary Treatment, and Chorination in the wastewater treatment train.

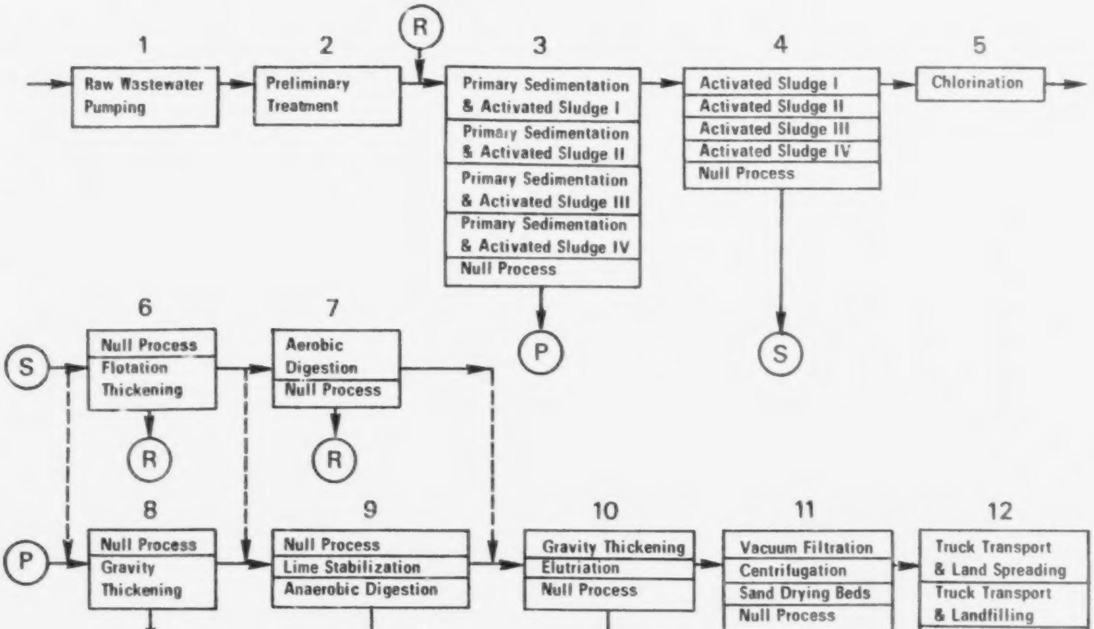
the low cost of dewatering on sand beds, the rather severe nitrogen limitation on the nearby sludge spreading site, and the absence of any air pollution controls on the incinerator. Note that designs 2 and 3 of the sensitivity phase are only 0.7 percent (0.2 ¢/1000 gal) more expensive. Design 3 uses landfilling instead of incineration and design 2 employs land spreading of liquid sludge.

It is interesting to observe the effect of the recycles from sludge treatment on the design choices in this problem. Had no account been taken of these recycles, design 1 of the optimization phase would have been designated as least-cost. Note that its true cost is 29.1 ¢/1000 gal. which is 5.4 percent more expensive than design 2.

The total computational effort for arriving at the results in Table 9 was estimated as being only 5.5 percent of that needed to evaluate all 15,360 alternatives one at a time. The solution time for this problem was approximately 360 seconds on a DEC PDP-11/70 computer.

CASE STUDY 2

The multi-option flow diagram for this example is shown in Figure 4. It represents an activated sludge system that features the options of returning the waste activated sludge to the primary clarifier or not using



R
1
2
3
4
5
Raw Wastewater Pumping
Preliminary Treatment
Primary Sedimentation & Activated Sludge I
Primary Sedimentation & Activated Sludge II
Primary Sedimentation & Activated Sludge III
Primary Sedimentation & Activated Sludge IV
Null Process
Activated Sludge I
Activated Sludge II
Activated Sludge III
Activated Sludge IV
Null Process
Chlorination
6
7
S
Null Process
Flotation Thickening
Aerobic Digestion
Null Process
P
S
R
R
8
9
10
11
12
P
Null Process
Gravity Thickening
Null Process
Lime Stabilization
Anaerobic Digestion
Gravity Thickening
Elutriation
Null Process
Vacuum Filtration
Centrifugation
Sand Drying Beds
Null Process
Truck Transport & Land Spreading
Truck Transport & Landfilling
Multiple Hearth Incineration
R

Figure 4. Multi-option flow diagram for case study 2

any primary sedimentation. Several different design levels for the activated sludge units have been considered. Note how the "null process" is used at stages 3 and 4 to allow a choice of one or the other of the two types of activated sludge options. The values of the input design parameters for the unit process options are given in Table 10. The options shown in Figure 4 can be arranged into 21,600 different systems. Once again EXEC/OP will be used to estimate the top five least-cost designs.

The results for this study are displayed in Table 11. Note that one of the "next best" designs (number 1) is actually lower in cost (by only 0.5 percent) than the best design found in the optimization phase (number 2). This is a result of the heuristic nature of the optimization algorithm of EXEC/OP and it demonstrates another advantage to using the next-best design feature of the program.

The least-cost design employs activated sludge at a mixed liquor volatile solids concentration of 3000 mg/l and a recycle ratio of 0.3 with the waste activated sludge returned to the primary sedimentation tank. Sludge processing consists of anaerobic digestion, gravity thickening, sand drying, and incineration. Total cost is 27.8 ¢/1000 gal. As mentioned above, substitution of landfilling for incineration increases costs by only 0.5 percent to 27.9 ¢/1000 gal. In comparison, the same design obtained in Case Study 1, where no recycling of waste activated sludge to primary sedimentation was considered, had a total cost of 27.6 ¢/1000 gal. Its energy production from anaerobic digestion was 419 kwh/mil. gal. as opposed to 354 kwh/mil. gal. for this case study. Thus for the design data used in these examples, there does not appear to be any advantage to returning waste activated sludge to the primary clarifier rather than mixing it with primary sludge prior to digestion.

The computations required to arrive at the results in Table 11 represented only 2.2 percent of the effort needed to evaluate all 21,600 possible designs individually. The solution time for this problem was 282 seconds on the DEC PDP 11/70 computer.

CASE STUDY 3

This example demonstrates how EXEC/OP can be used to "fine tune" the design levels of the process units in a system design. The process units chosen as the least-cost alternative for Case Study 1 will be used for this purpose. Figure 5 shows the multi-option flow diagram for this problem. The design levels for the primary sedimentation, activated sludge, anaerobic digestion, and gravity thickening units are to be refined so that total system cost is minimized. The design option denoted as number I for each of these units corresponds to the design level associated with the least-cost system of Case Study 1. Recall that the total cost of this system was 27.6 ¢/1000 gal. The treatment stages in this flow diagram have been set up to be compatible with those of Case Study 1. Because of this the "null process" units at stages 7 and 8 are redundant and could be eliminated if so desired (leaving a system with 10 stages instead of 12).

TABLE 10. INPUT PROCESS DESIGN PARAMETERS FOR CASE STUDY 2

PRI = primary sludge WAS = waste activated sludge MIX = PRI + WAS

Process	Design Parameter	Value
Pumping	See Table 7	
Preliminary Treatment	See Table 7	
Primary Sedimentation	TSS removal, %	50.0
Activated Sludge I[a]	MLVSS, mg/l	2000.0
	Recycle ratio	0.3
Activated Sludge II	MLVSS, mg/l	2000.0
	Recycle ratio	0.5
Activated Sludge III	MLVSS, mg/l	3000.0
	Recycle ratio	0.3
Activated Sludge IV	MLVSS, mg/l	3000.0
	Recycle ratio	0.5
Chlorination	See Table 7	
Air Flotation Thickening	See Table 7	
Aerobic Digestion	Detention time, days	10.0
Gravity Thickening	Solids recovery ratio	0.9
	Underflow TSS, %	2.0 (WAS) 5.0 (MIX)
	Loading, lb/day/sq. ft.	6.0 (WAS) 8.0 (MIX)
Anaerobic Digestion	Detention time, days	15.0
Lime Stabilization	See Table 7	

---

[a] All activated sludge alternatives are also required to attain an effluent quality of 30 mg/l BOD_5 and 30 mg/l TSS

(continued)

TABLE 10 (continued)

Process	Design Parameter	Value
Elutriation	Solids recovery ratio	0.76
	Underflow TSS, %	2.0 (WAS)
		4.0 (MIX)
	Loading, lb/day/sq. ft.	6.0 (WAS)
		8.0 (MIX)
	Washwater ratio	3.0
Vacuum Filtration	Loading, gph/sq. ft.	10.0
	Chemical dosage, %	See Table 8
Centrifugation	Solids recovery ratio	See Table 8
	Cake solids, %	"
	Feed rate, gpm	"
Sand Drying Beds	See Table 7	
Land Spreading	One way haul distance, miles	10.0
	Cost of land, $/acre	3000.0
	N application rate, lb/acre/yr	400.0
	Site preparation cost, $/acre	500.0
	Spreading cost, $/dry ton	10.0
Landfilling	See Table 7	
Incineration	See Table 7	

TABLE 11. LEAST-COST DESIGNS FOR CASE STUDY 2

Design	Wastewater Process Selections[a]	Sludge Process Selections	Total Cost, ¢/1000 gal.	Gross Energy Consumption, kwh/mil. gal.	Energy Production, kwh/mil. gal.
Optimization Phase					
1	Primary Sedimentation + Activated Sludge III	Anaerobic Digestion Elutriation Land Spreading	28.9	1278	356
2	Primary Sedimentation + Activated Sludge III	Anaerobic Digestion Gravity Thickening Sand Drying Beds Landfilling	27.9	1217	354
3	Same as Design 2				
Sensitivity Phase					
1	Primary Sedimentation + Activated Sludge III	Anaerobic Digestion Gravity Thickening Sand Drying Beds Incineration	27.8	1299	354
2	Same as Design 2 of Optimization Phase		27.9	1217	354

---

[a] All designs utilize Pumping, Preliminary Treatment, and Chlorination in the wastewater treatment train.

(continued)

TABLE 11 (continued)

Design	Wastewater Process Selections[a]	Sludge Process Selections	Total Cost, ¢/1000 gal.	Gross Energy Consumption, kwh/mil. gal.	Energy Production, kwh/mil. gal
3	Primary Sedimentation + Activated Sludge IV	Anaerobic Digestion Gravity Thickening Sand Drying Beds Incineration	28.1	1331	354
4	Primary Sedimentation + Activated Sludge IV	Anaerobic Digestion Gravity Thickening Sand Drying Beds Landfilling	28.2	1249	354
5	Primary Sedimentation + Activated Sludge III	Anaerobic Digestion Gravity Thickening Land Spreading	28.3	1261	354

[a] All designs utilize Pumping, Preliminary Treatment, and Chlorination in the wastewater treatment train.

TABLE 12. INPUT PROCESS DESIGN PARAMETERS FOR CASE STUDY 3

Process	Design Parameter	Value
Pumping	See Table 7	
Preliminary Treatment	See Table 7	
Primary Sedimentation I	TSS removal, %	60.0
Primary Sedimentation II	TSS removal, %	50.0
Primary Sedimentation III	TSS removal, %	55.0
Activated Sludge I[a]	MLVSS, mg/l Recycle ratio	3000.0 0.3
Activated Sludge II	MLVSS, mg/l Recycle ratio	2500.0 0.3
Activated Sludge II	MLVSS, mg/l Recycle ratio	2500.0 0.3
Activated Sludge III	MLVSS, mg/l Recycle ratio	3500.0 0.3
Activated Sludge IV	MLVSS, mg/l Recycle ratio	2500.0 0.35
Activated Sludge V	MLVSS, mg/l Recycle ratio	3000.0 0.35
Activated Sludge VI	MLVSS, mg/l Recycle ratio	3500.0 0.35
Activated Sludge VII	MLVSS, mg/l Recycle ratio	2500.0 0.25
Activated Sludge VIII	MLVSS, mg/l Recycle ratio	3000.0 0.25

[a] All activated sludge alternatives are also required to attain an effluent quality of 30 mg/l BOD_5 and 30 mg/l TSS

(continued)

TABLE 12 (continued)

Process	Design Parameter	Value
Activated Sludge IX	MLVSS, mg/l	3500.0
	Recycle ratio	0.25
Chlorination	See Table 7	
Anaerobic Digestion I	Detention time, days	15.0
Anaerobic Digestion II	Detention time, days	12.0
Anaerobic Digestion III	Detention time, days	17.0
Gravity Thickening I	Solids recovery ratio	0.9
	Underflow TSS, %	5.0
	Loading, lb/day/sq. ft.	8.0
Gravity Thickening II	Solids recovery ratio	0.9
	Underflow TSS, %	4.0
	Loading, lb/day/sq. ft.	12.0
Gravity Thickening III	Solids recovery ratio	0.9
	Underflow TSS, %	7.0
	Loading, lb/day/sq. ft.	5.0
Sand Drying Beds	See Table 7	
Incineration	See Table 7	

[a] All activated sludge alternatives are also required to attain an effluent quality of 30 mg/l BOD_5 and 30 mg/l TSS

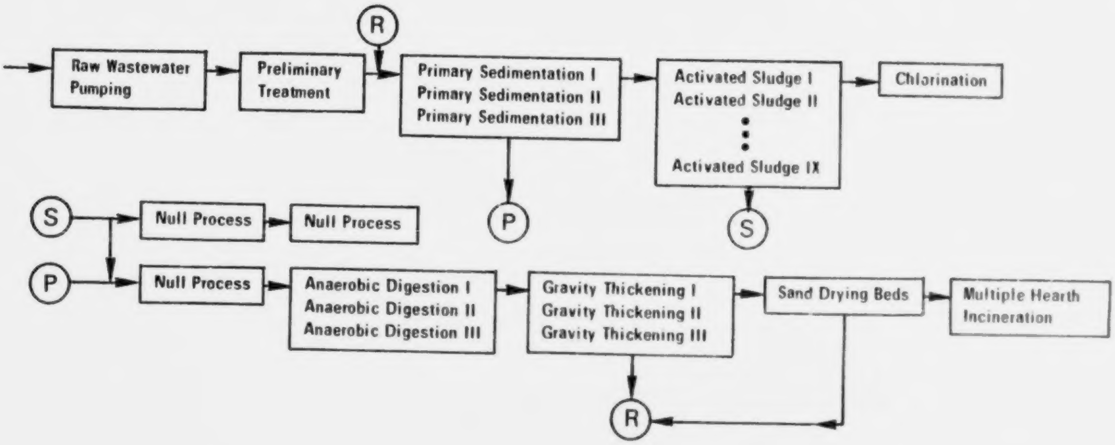

R
Raw Wastewater Pumping
Preliminary Treatment
Primary Sedimentation I
Primary Sedimentation II
Primary Sedimentation III
Activated Sludge I
Activated Sludge II
Activated Sludge IX
Chlorination
P
S
S
Null Process
Null Process
P
Null Process
Anaerobic Digestion I
Anaerobic Digestion II
Anaerobic Digestion III
Gravity Thickening I
Gravity Thickening II
Gravity Thickening III
Sand Drying Beds
Multiple Hearth Incineration
R

Figure 5. Multi-option flow diagram for case study 3

The significant input design parameter values associated with the unit process options are given in Table 12. The resulting least-cost selection arrived at by EXEC/OP is shown in Table 13. Since only the single least-cost design is desired there is no sensitivity phase listing for this example. Only two iterations on the recycle penalty values were needed to reach a design whose total cost is 26.95 ¢/1000 gal. This gives only a 2.4 percent savings over the initial design. The improved design indicates that one should try to remove as much solids as possible in primary sedimentation, use the highest solids concentration and lowest recycle ratio in activated sludge, use the minimum amount of digestion time and thicken to the greatest extent possible. The CPU time required for this problem was 26.63 seconds on the DEC PDP 11/70.

TABLE 13. LEAST-COST DESIGN FOR CASE STUDY 3

Design	Wastewater Process Selections	Sludge Process Selections	Total Cost ¢/1000 gal.	Gross Energy Consumption, kwh/mil gal.	Energy Production, kwh/mil gal.
1	Pumping Preliminary Treatment Primary Sedimentation I Activated Sludge IV Chlorination	Anaerobic Digestion II Gravity Thickening III Sand Drying Beds Incineration	26.95	1240	414
2	Same as Design 1				

The results of this case study leads one to speculate on the relative importance of system structural choices versus individual unit design choices. It may be that in general the former are more critical. This would follow as a result of the fact that the acceptable ranges of the design parameters for most processes are usually fairly small and, as borne out in this example, the total system resource utilization will be relatively insensitive to adjustments in the design of a single process unit.

CASE STUDY 4

This example demonstrates the single design evaluation feature of EXEC/OP. Detailed performance is to be obtained for the least-cost design arrived at in Case Study 3. This simply requires that the EXEC/OP input data for Case Study 3 be re-run with the addition of two lines of data that specify the choice of process options at each stage of the system to be analyzed.

The results of running EXEC/OP on this problem are shown in the printout reproduced in Figure 6. Summaries of the process options, the selection criteria, and the economic parameters are first presented. Note that each process option is identified by a user assigned option number, a standard process code number, and the number of the stage at which the process appears. Next there appears a listing of the criterion values associated with the process option chosen at each stage of the system. This is followed by a detailed listing of the input and computed output design parameter values and the composition of the influent, effluent, and sidestream waste streams for each process. For reasons of programming economy, the process design data are listed in the order in which they are specified for each process description given in Appendix C without any additional explanatory headings. The headings on the waste stream constituents correspond to the abbreviations used in Table 4.

CASE STUDY 5

The examples presented up until now have all been single objective design problems, i.e., minimize total cost. In this case study the conflicting objectives of minimizing cost and minimizing energy consumption will be considered. It is shown how EXEC/OP can be used to efficiently identify those system designs that offer meaningful trade-offs between these two objectives. The implication behind a cost/energy-effectiveness analysis is that the market price of energy or fuel does not represent its true social value as a scarce resource and that the least-cost design will not also be the least-energy design.

The set of design options to be used in this example is the same as used in Case Study 1 (see Figure 3). The analysis is performed by making a series of runs with EXEC/OP in which total cost is minimized while energy consumption is constrained not to exceed a specified target level. As the target level is varied, systems with different cost-energy combinations will be generated. None of these designs will be inferior in the sense that there will exist some other design that has both lower values of cost and

```
                    EXECUTIVE PROGRAM
                  (OPTIMIZATION VERSION)
                           FOR
      PRELIMINARY SYNTHESIS OF WASTE TREATMENT SYSTEMS

          U.S. ENVIRONMENTAL PROTECTION AGENCY
        MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
          SYSTEMS AND ECONOMIC ANALYSIS SECTION
                 CINCINNATI, OHIO 45268


                      CASE STUDY 4


                                    PROCESS ALTERNATIVES
                                    --------------------

OPTION  PROCESS  STAGE  SIDESTREAM
  NO.     NO.     NO.   DESTINATION                          REMARKS
------  -------  -----  -----------  ------------------------------------------------------
   1      15       1        8        RAW WASTEWATER PUMPING
   2       1       2        8        PRELIMINARY TREATMENT
   3       2       3        8        PRIMARY SEDIMENTATION (50% SOLIDS REMOVAL)
   4       2       3        8                              (55% SOLIDS REMOVAL)
   5       2       3        8                              (60% SOLIDS REMOVAL)
   6       3       4        6        ACTIVATED SLUDGE (MLVSS=2500, R=.3)
   9       3       4        6                         (MLVSS=3000, R=.3)
  10       3       4        6                         (MLVSS=3500, R=.3)
  11       3       4        6                         (MLVSS=2500, R=.35)
  12       3       4        6                         (MLVSS=3000, R=.35)
  13       3       4        6                         (MLVSS=3500, R=.35)
  14       3       4        6                         (MLVSS=2500, R=.25)
  15       3       4        6                         (MLVSS=3000, R=.25)
  16       3       4        6                         (MLVSS=3500, R=.25)
  17      12       5        6        CHLORINATION (8 MG/L DOSAGE)
  30       0       6        3        NULL PROCESS
  30       0       7        3        NULL PROCESS
  30       0       8        3        NULL PROCESS
  18       6       9        3        ANAEROBIC DIGESTION (15 DAYS)
  19       6       9        3                            (12 DAYS)
  20       6       9        3                            (17 DAYS)
  21       8      10        3        GRAVITY THICKENING (TO 5% SOLIDS)
  22       8      10        3                           (TO 4% SOLIDS)
  23       8      10        3                           (TO 7% SOLIDS)
  24      10      11        3        SAND DRYING BEDS (30% CAKE SOLIDS)
  25      11      12        3        INCINERATION (2 LB/HR/SQ FT)
```

Figure 6. EXEC/OP output for case study 4

```
                          SELECTION CRITERIA
                          ------------------

         CRITERION                        WEIGHT        LIMIT
         ---------                        ------        -----

     1,  INITIAL CONSTR, COST, M$          0,00       10000,00
     2,  ANNUAL O & M COST, $/MG           0,00       10000,00
     3,  TOTAL ANNUAL COST, $/MG           1,00       10000,00
     4,  ENERGY CONSUMED, KWH/MG           0,00       10000,00
     5,  ENERGY PRODUCED, KWH/MG           0,00           0,00
     6,  NET ENERGY CONSUMED, KWH/MG       0,00       10000,00
     7,  LAND REQUIRED, ACRES              0,00       10000,00
     8,  UNDESIRABILITY INDEX              0,00       10000,00


                            ECONOMIC DATA
                            -------------

            CONSTRUCTION COST INDEX                2,8800
            WHOLESALE PRICE INDEX                  2,0000
            DIRECT HOURLY WAGE, $/HR               5,9100
            FRACTION CHARGED TO SUPERVISION        0,1500
            COST ESCALATOR FOR MISC, FEES          1,3300
            COST OF ELECTRICITY, $/KWH             0,0330
            FUEL CONVERSION EFFICIENCY             0,3100
            DISCOUNT RATE                          0,0637
            CAPITAL RECOVERY FACTOR                0,0899

STAGE  PROCESS  SLUDGE,                                        SELECTION CRITERIA
 NO,   OPTION   TONS/DAY        1         2         3         4         5         6         7         8
-----  -------  --------    --------- --------- --------- --------- --------- --------- --------- ---------
  1       1         0,00       0,91     10,09     32,39    141,37      0,00    141,37      0,00      0,00
  2       2         0,00       0,28      9,36     16,15      5,22      0,00      5,22      0,00      0,00
  3       5         6,68       0,59     12,37     26,88      8,71      0,00      8,71      0,00      0,00
  4      16         1,69       1,48     47,26     83,59    625,09      0,00    625,09      0,00      0,00
  5      17         0,00       0,29     17,52     24,65    120,53      0,00    120,53      0,00      0,00
  9*     19         8,37       0,52      5,44     18,33    236,55    413,99   -177,44      0,00      0,00
 10      23         4,39       0,14      1,88      5,21      1,53      0,00      1,53      0,00      0,00
 11      24         3,95       0,32     19,60     27,54      0,90      0,00      0,90      0,89      0,00
 12      25         3,95       0,88     13,05     34,78     99,66      0,00     99,66      0,00      0,00
                --------    --------- --------- --------- --------- --------- --------- --------- ---------
SYSTEM VALUES       8,37       5,40    136,57    269,51   1239,56    413,99    825,57      0,89      0,00
```

Figure 6. (continued)

```
                                    PROCESS PERFORMANCE CHARACTERISTICS
                                    -----------------------------------

                                            VOLUME FLOW, MGD
                                            CONCENTRATION, MG/L
                     CONSULT PROGRAM REFERENCE MANUAL FOR MEANING OF PROCESS INPUT AND OUTPUT DESIGN DATA.

                                         STAGE  1   PROCESS OPTION  1
                                         ----------------------------

                                                  INPUT DESIGN DATA:
   30.000        0.000        0.000        0.000        0.000        0.000        0.000        0.000
    0.000        0.000        0.000        0.000        0.000        0.000        0.000        1.000

                                                  OUTPUT DESIGN DATA:
   14.805        0.000        0.000        0.000        0.000        0.000        0.000        0.000        0.000
    0.000        0.000        0.000        0.000        0.000        0.000        0.000        0.000        0.000
    0.000        0.000

                               INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:
      Q           SOC          SNBC         SON          SOP          SFM          SBOD         VSS          TSS
   10.000      105.000       30.000       10.000        2.000       30.000      140.000      229.000      254.000
   10.000      105.000       30.000       10.000        2.000       30.000      140.000      229.000      254.000
    0.000        0.000        0.000        0.000        0.000        0.000        0.000        0.000        0.000
     DOC          DNBC          DN           DP           DFM          ALK          DBOD         NH3          NO3
   43.000       11.000       19.000        4.000      500.000      250.000       60.000       15.000        0.000
   43.000       11.000       19.000        4.000      500.000      250.000       60.000       15.000        0.000
    0.000        0.000        0.000        0.000        0.000        0.000        0.000        0.000        0.000

                                         STAGE  2   PROCESS OPTION  2
                                         ----------------------------

                                                  INPUT DESIGN DATA:
    1.000        0.000        0.000        0.000        0.000        0.000        0.000        0.000
    0.000        0.000        0.000        0.000        0.000        0.000        0.000        1.000

                                                  OUTPUT DESIGN DATA:
    0.000        0.000        0.000        0.000        0.000        0.000        0.000        0.000        0.000
    0.000        0.000        0.000        0.000        0.000        0.000        0.000        0.000        0.000
    0.000        0.000

                               INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:
      Q           SOC          SNBC         SON          SOP          SFM          SBOD         VSS          TSS
   10.000      105.000       30.000       10.000        2.000       30.000      140.000      229.000      254.000
   10.049      108.567       33.639       10.425        2.073       33.330      139.866      237.592      265.946
    0.000        0.000        0.000        0.000        0.000        0.000        0.000        0.000        0.000
     DOC          DNBC          DN           DP           DFM          ALK          DBOD         NH3          NO3
   43.000       11.000       19.000        4.000      500.000      250.000       60.000       15.000        0.000
   43.625       11.000       22.409        4.915      500.000      262.173       61.167       15.013        0.000
    0.000        0.000        0.000        0.000        0.000        0.000        0.000        0.000        0.000
```

Figure 6. (continued)

```
                                      STAGE  3   PROCESS OPTION  5
                                      -------------------------

                                            INPUT DESIGN DATA:
    0.600      200.000       14.000       0.000      0.000      0.000      0.000      0.000
    0.000        0.000        0.000       0.000      0.000      0.000      1.000      1.000

                                           OUTPUT DESIGN DATA:
  868.395       11.572      251.229       0.000      0.000      0.000      0.000      0.000      0.000
    0.000        0.000        0.000       0.000      0.000      0.000      0.000      0.000      0.000
    0.000        0.000

                            INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:
      Q          SOC         SNBC        SON        SOP        SFM        SBOD        VSS        TSS
   10.049      108.567       33.639     10.425      2.073     33.330    139.866    237.592    265.946
   10.019       43.557       13.496      4.182      0.832     13.372     56.115     95.323    106.698
    0.030    21713.410     6727.855   2084.939    414.547   6665.948  27973.236  47518.363  53189.203
    DOC         DNBC           DN         DP        DFM        ALK        DBOD        NH3        NO3
   43.625       11.000       22.409      4.915    500.000    262.173     61.167     15.013      0.000
   43.625       11.000       22.409      4.915    500.000    262.173     61.167     15.013      0.000
   43.625       11.000       22.409      4.915    500.000    262.173     61.167     15.013      0.000



                                      STAGE  4   PROCESS OPTION 16
                                      -------------------------

                                            INPUT DESIGN DATA:
   30.000       30.000     3500.000       0.250    200.000      0.500     10.000      0.480
    7.000        0.050      800.000      30.000      1.000      1.000      1.000      1.000

                                           OUTPUT DESIGN DATA:
  117.282        4.154        0.007      13.573     10.000      0.266      0.678      0.678   1381.824
    0.000     2118.176      305.168     820.827     94.737      0.250      7.000 9888385.000  6866.934
    0.987        2.505

                            INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:
      Q          SOC         SNBC        SON        SOP        SFM        SBOD        VSS        TSS
   10.019       43.557       13.496      4.182      0.832     13.372     56.115     95.323    106.698
   10.000       10.513        7.393      2.034      0.240      5.699      7.445     24.301     30.000
    0.019     7472.423     5254.837   1445.460    170.477   4050.645   5291.604  17271.926  21322.572
    DOC         DNBC           DN         DP        DFM        ALK        DBOD        NH3        NO3
   43.625       11.000       22.409      4.915    500.000    262.173     61.167     15.013      0.000
   17.271       11.000       21.819      5.183    500.000    262.173     22.545     21.819      0.000
   17.271       11.000       21.819      5.183    500.000    262.173     22.545     21.819      0.000
```

Figure 6. (continued)

```
                                   STAGE  5   PROCESS OPTION 17
                                   -------------------------

                                         INPUT DESIGN DATA:
    8.000      30.000     220.000      2.500    180.000      0.000      0.000      0.000
    0.000       0.000       0.000      0.000      0.000      1.000      1.000      1.000

                                         OUTPUT DESIGN DATA:
27852.041     121.618      38.006      0.000      0.000      0.000      0.000      0.000      0.000
    0.000       0.000       0.000      0.000      0.000      0.000      0.000      0.000      0.000
    0.000       0.000

                        INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:
      Q          SOC        SNBC        SON        SOP        SFM       SBOD        VSS        TSS
   10.000      10.513       7.393      2.034      0.240      5.699      7.445     24.301     30.000
   10.000      10.513       7.393      2.034      0.240      5.699      7.445     24.301     30.000
    0.000       0.000       0.000      0.000      0.000      0.000      0.000      0.000      0.000
     DOC        DNBC         DN          DP        DFM        ALK       DBOD        NH3        NO3
   17.271      11.000      21.819      5.183    500.000    262.173     22.545     21.819      0.000
   17.271      11.000      21.819      5.183    500.000    262.173     22.545     21.819      0.000
    0.000       0.000       0.000      0.000      0.000      0.000      0.000      0.000      0.000

                                   STAGE  9   PROCESS OPTION 19
                                   -------------------------

                                         INPUT DESIGN DATA:
   12.000      30.000       0.500      0.310      0.000      0.000      0.000      0.000
    0.000       0.000       0.000      0.000      0.000      0.000      0.000      1.000

                                         OUTPUT DESIGN DATA:
    0.234    1154.105      78.854  75964.641  39894.750      0.000      0.000      0.000      0.000
    0.000       0.000       0.000      0.000      0.000      0.000      0.000      0.000      0.000
    0.000       0.000

                        INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:
      Q          SOC        SNBC        SON        SOP        SFM       SBOD        VSS        TSS
    0.049   16207.044    6158.303   1837.681    320.176   5654.725  19203.240  35823.391  40867.770
    0.049    6637.448    6158.303    770.373    134.221   5654.725    896.000  15797.126  21451.852
    0.000       0.000       0.000      0.000      0.000      0.000      0.000      0.000      0.000
     DOC        DNBC         DN          DP        DFM        ALK       DBOD        NH3        NO3
   33.435      11.000      22.181      5.018    500.000    262.173     46.234     17.645      0.000
  170.715      11.000     715.931    190.974    500.000   2738.860    298.667     17.645      0.000
    0.000       0.000       0.000      0.000      0.000      0.000      0.000      0.000      0.000
```

Figure 6. (continued)

```
                                    STAGE 12   PROCESS OPTION 25
                                    --------------------------

                                         INPUT DESIGN DATA:
   2.000      2.000     35.000      5.000      0.000  10000.000      1.000      0.300
   1.000      0.000      0.000      0.000      0.000      0.000      0.000      1.000

                                         OUTPUT DESIGN DATA:
 411.000 198371.703   7904.947   3073.583   7955.021      0.000      0.000      0.000      0.000
   0.000      0.000      0.000      0.000      0.000      0.000      0.000      0.000      0.000
   0.000      0.000

                          INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:
     Q         SOC        SNBC        SON        SOP        SFM        SBOD        VSS        TSS
   0.003  90171.328  83662.039  10465.706   1823.422  76820.797  12172.380 214607.750 300000.000
   0.049    834.422    774.187     96.847     16.873    710.880    112.640   1985.925   2696.804
   0.000      0.000      0.000      0.000      0.000      0.000      0.000      0.000      0.000
    DOC       DNBC         DN         DP        DFM        ALK       DBOD        NH3        NO3
 170.715     11.000    715.931    190.974    500.000   2738.860    298.667     17.645      0.000
 170.715     11.000    715.931    190.974    500.000   2738.861    298.667     17.645      0.000
   0.000      0.000      0.000      0.000      0.000      0.000      0.000      0.000      0.000
```

Figure 6. (continued)

```
                                 STAGE 10   PROCESS OPTION 23
                                 --------------------------

                                     INPUT DESIGN DATA:
    0.900   70000.000     700.000       5.000   70000.000   70000.000   70000.000       5.000
    5.000       5.000       0.000       0.000       0.000       0.000       0.000       1.000

                                     OUTPUT DESIGN DATA:
 1756.655       0.000       0.000       0.000       0.000       0.000
    0.000       0.000       0.000       0.000       0.000       0.000       0.000       0.000       0.000
    0.000       0.000                                                   0.000       0.000       0.000

                      INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:
        Q         SOC        SNBC         SON         SOP         SFM        SBOD         VSS         TSS
    0.049    6637.448    6158.303     770.373     134.221    5654.725     896.000   15797.126   21451.852
    0.014   21658.799   20095.293    2513.822     437.979   18452.055    2923.758   51547.941   70000.000
    0.036     916.534     850.371     106.377      18.534     780.834     123.724    2181.350    2962.184
      DOC        DNBC          DN          DP         DFM         ALK        DBOD         NH3         NO3
  170.715      11.000     715.931     190.974     500.000    2738.860     298.667      17.645       0.000
  170.715      11.000     715.931     190.974     500.000    2738.860     298.667      17.645       0.000
  170.715      11.000     715.931     190.974     500.000    2738.860     298.667      17.645       0.000

                                 STAGE 11   PROCESS OPTION 24
                                 --------------------------

                                     INPUT DESIGN DATA:
    0.300    2000.000       0.300       0.300       0.300      15.000       1.000    3000.000
    0.000       0.000       0.000       0.000       0.000       0.000       0.000       1.000

                                     OUTPUT DESIGN DATA:
40519.719       0.000       0.000       0.000       0.000       0.000
    0.000       0.000       0.000       0.000       0.000       0.000       0.000       0.000       0.000
    0.000       0.000                                                   0.000       0.000       0.000

                      INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:
        Q         SOC        SNBC         SON         SOP         SFM        SBOD         VSS         TSS
    0.014   21658.799   20095.293    2513.822     437.979   18452.055    2923.758   51547.941   70000.000
    0.003   90171.328   83662.039   10465.706    1823.422   76820.797   12172.380  214607.750  300000.000
    0.014     618.823     574.151      71.823      12.514     527.202      83.536    1472.798    2000.000
      DOC        DNBC          DN          DP         DFM         ALK        DBOD         NH3         NO3
  170.715      11.000     715.931     190.974     500.000    2738.860     298.667      17.645       0.000
  170.715      11.000     715.931     190.974     500.000    2738.860     298.667      17.645       0.000
  170.715      11.000     715.931     190.974     500.000    2738.860     298.667      17.645       0.000
```

Figure 6. (continued)

energy. It is only from this reduced, non-inferior set of alternatives that trade-offs between cost and energy need to be made to arrive at a final design decision [27].

The concept of the non-inferior or efficient set of alternatives in a multi-objective design problem is graphically illustrated in Figure 7. This figure considers a case where there are only ten feasible system designs and plots the position of each alternative on a set of cost-energy axes. Consider a comparison between alternative A and alternative B. No meaningful trade-off exists since B dominates A in both cost and energy. A is said to be inferior to B and can be discarded from the decision making process, providing that cost-and energy-effectiveness are the only decision criteria. The non-inferior or efficient set of designs are those that are not inferior to any other design. By inspection we see that alternatives B, D, F, and H form the non-inferior set for Figure 7. All other alternatives could be ignored.

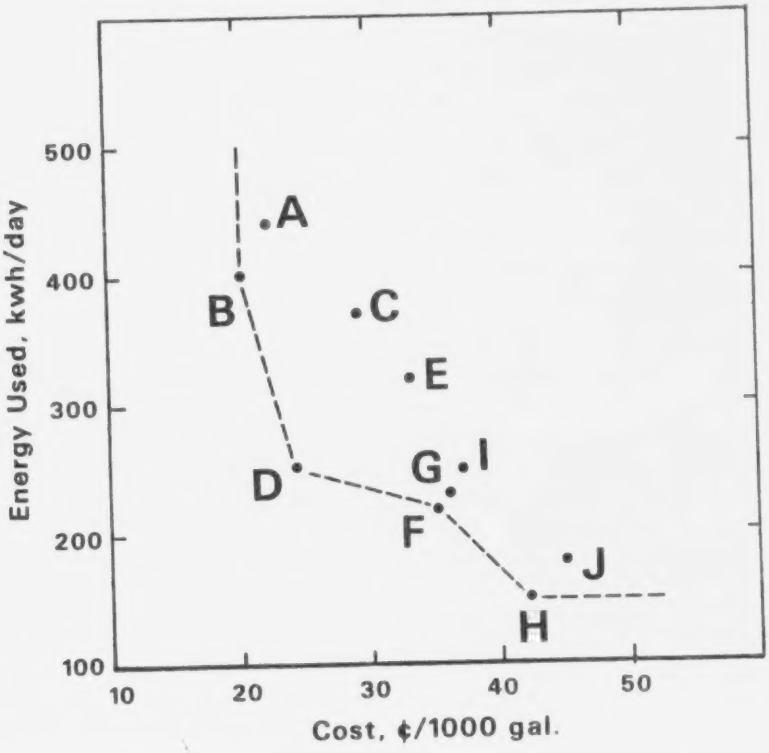


Figure 7. Illustration of the non-inferior set

For the ten designs considered in Figure 7 it was possible to identify the non-inferior set by inspection. Had there been a larger number of alternatives and objectives a more systematic procedure would be needed. The constraint method, as described above, wherein cost is minimized while energy is constrained not to exceed various target levels, is one such procedure. Thus in Figure 7, if we minimize cost and constrain energy to not exceed 150 kwh/day we obtain alternative H; for energy constrained anywhere between 150 and 220 kwh/day alternative F is identified; and so on. Of course a final choice between systems B, D, F, and H would depend on the designer's subjective preferences regarding the relative value of the cost and energy figures for these designs. Although the concept of non-inferiority was demonstrated here for only two objectives it also applies to higher dimensional problems as well.

Referring back to the process options of Figure 3, EXEC/OP was used to perform a cost/energy-effectiveness analysis for two different conditions: a) no energy recovery was practiced and b) digester gas was converted into electricity with 31 percent efficiency at a net credit of 0.011 \$/kwh (the commercial price of electricity minus an assumed conversion cost of 0.022 \$/kwh). In both cases the same EXEC/OP input data as in Case Study 1 (Tables 7 and 8) was used with the following exceptions. With no energy recovery, the value of the constraint limit on gross energy consumption was reduced from one run to the next to obtain a series of least-cost designs under progressively tighter energy constraints. A similar procedure was followed for the case of digester gas recovery except that the weighting coefficient for energy production was set equal to the cost credit of 0.011 \$/kwh and the net energy consumption constraint limit was reduced at each successive run of EXEC/OP.

As an example of the type of results obtained from this procedure, Table 14 summarizes the EXEC/OP output for the case where net energy consumption (with digester gas recovery) was constrained to be at or below 850 kwh/mil. gal. Note that the first design arrived at in the optimization phase is infeasible because its net energy consumption is 911 kwh/mil. gal. The best design is found to be number 2. In comparison with the least-cost, energy unconstrained design it substitutes landfilling for incineration of sludge, thus reducing net energy consumption from 888 kwh/mil. gal. to 806 kwh/mil. gal. Note that the objective function values for this design equals the total cost of the system, 27.76 ¢/1000 gal. minus the energy credit of 0.011 \$/kwh times 418.9 kwh/mil. gal. (the energy content of the digester gas), or 0.46 ¢/1000 gal. giving a total of 27.3 ¢/1000 gal.

The results of the cost/energy-effectiveness analysis are summarized in Table 15. All of these non-inferior designs utilize the same wastewater treatment - 60 percent solids removal in primary sedimentation and activated sludge with 3000 mg/l MLVSS and 30 percent recycle. As an example of the kinds of trade-offs that these alternative systems present, consider those with no energy recovery. Table 15 shows that a maximum energy reduction of 23 percent can be realized at a 16 percent increase in system cost by going from system 1a to system 5a. A more attractive trade-off may be with system 2a which offers a 6.3 percent energy reduction for less than a one

TABLE 14. LEAST-COST ENERGY CONSTRAINED DESIGN FOR CASE STUDY 5

Design	Wastewater Process Selections	Sludge Process Selections	Objective Value	Total Cost ¢/1000 gal.	Net Energy Consumption kwh/mil gal.	Energy Production kwh/mil gal.
Optimization Phase						
1	Primary Sedimentation II Activated Sludge III	Anaerobic Digestion I Elutriation Sand Drying Beds Incineration	27.68	28.1	911.3	421.4
2	Primary Sedimentation II Activated Sludge III	Anaerobic Digestion I Gravity Thickening Sand Drying Beds Landfilling	27.30	27.76	806.0	418.9
3	Primary Sedimentation II Activated Sludge III	Anaerobic Digestion I Gravity Thickening Land Spreading I	27.31	27.77	846.9	418.1
4	Same as Design 3					

[a] All designs utilize Pumping, Preliminary Treatment, and Chlorination in the wastewater treatment train.

TABLE 15. NON-INFERIOR COST/ENERGY SYSTEMS FOR CASE STUDY 5

System	Air Flotation Thickening	Anaerobic Digestion. I (15 days)	Lime Stabilization	Gravity Thickening	Centrifugation	Sand Drying Beds	Incineration	Landfilling	System Cost, ¢/1000 gal.	System Net Energy, kwh/mil. gal.
No Energy Recovery										
1a		MIX		MIX		MIX	MIX		27.6	1307
2a		MIX		MIX		MIX		MIX	27.8	1225
3a			MIX		MIX			MIX	30.7	1090
4a					MIX			MIX	31.5	1033
5a			MIX			MIX		MIX	31.9	1009
Recovery of Methane										
1b		MIX		MIX		MIX	MIX		27.2	888
2b		MIX		MIX		MIX		MIX	27.3	806
3b	WAS	MIX		MIX		MIX		MIX	27.6	734

PRI = primary sludge   WAS = waste activated sludge   MIX = PRI + WAS

Note: All systems utilize the same wastewater treatment train - Pumping, Preliminary Treatment, Primary Sedimentation II (60% solids removal), Activated Sludge III (3000 mg/l MLVSS and 30% recycle), and Chlorination.

percent increase in cost. Of course the final choice will depend on the designer's feelings regarding the relative importance of these objectives as well as any other criteria that are relevant to the design process.

The computer runs made for this case study averaged about 2.5 minutes of CPU time each on a DEC PDP-11/70 computer. From three to four iterations on the penalty terms for sludge treatment recycle streams per run were needed. In addition, each run was asked to identify the five most least-costly solutions. It is estimated that on the average, the computational effort required of each run was only 2.5 percent of that needed to evaluate all 15,360 possible system arrangements individually.

Hopefully these case studies have shown how EXEC/OP can be used as a practical tool for the preliminary synthesis of waste treatment systems. Perhaps its most productive use would be to generate alternative system designs that emphasize different objectives in various degrees. It can also be used to explore the sensitivity of these designs to uncertainty in various process performance parameters. The information derived from such analyses would ultimately enter into the value trade-off process that culminates in a final design decision.

REFERENCES

1. Eilers, R. G., et al., "Applications of Computer Programs in the Preliminary Design of Wastewater Treatment Facilities - Section II", EPA-600/2-78-185b, U. S. Environmental Protection Agency, Municipal Environmental Research Laboratory, Cincinnati, Ohio (1978).

2. Hendry, J. E., Rudd, D. F. and Seader, J. D., "Synthesis in the Design of Chemical Processes", AIChE Jour., 19, 1 (1973).

3. "LA/OMA Project Phase I Report", Regional Wastewater Solids Management Program, Los Angeles/Orange County Metropolitan Area, August (1976).

4. "Clean Water Act of 1977", Public Law 95-217, United States Congress, (1977).

5. Smith, R., "Preliminary Design and Simulation of Conventional Wastewater Renovation Systems Using the Digital Computer", Water Pollution Control Research Series Pub. No. WP-20-9, U.S. Department of Interior, Federal Water Pollution Control Administration, Cincinnati, Ohio (1968).

6. Silveston, P. L., "Digital Computer Simulation of Waste Treatment Plants Using the WATCRAP-PACER System", Water Poll. Control, 69, 686 (1970).

7. Chen, G. K., Fan, L. T. and Erickson, L. E., "Computer Software for Waste Water Treatment Plant Design", Jour. Water Poll. Control Fed., 44, 746 (1972).

8. Shoemaker, T. E. and Barkley, W. A., "Interactive Computer Design of Wastewater Plants," Jour. Environ. Eng. Div., Proc. Amer. Soc. Civil Engr., 103, 919 (1977).

9. Bennet, E. R., Rein, D. A., and Linstedt, K. D., "Economic Aspects of Sludge Dewatering and Disposal", Jour. Environ. Eng., Div., Amer. Soc. Civil Engr., 99, 55 (1973).

10. Kos, P., Meier, P. M. and Joyce, J. M., "Economic Analysis of the Processing and Disposal of Refuse Sludges", EPA-670/2-74-037, U.S. Environmental Protection Agency, National Environmental Research Center, Cincinnati, Ohio (1974).

11. Smith, R. and Eilers, R. G., "Computer Evaluation of Sludge Handling and Disposal Costs", Proceedings of the 1975 National Conference on Municipal Sludge Management and Disposal, Anaheim, California, August 18-20 (1975).

12. Burley, M. J. and Bayley, R. W., "Sludge Disposal Strategy: Processes and Costs", Water Poll. Control, 76, 205 (1977).

13. San Francisco Bay Region Wastewater Solids Study, "Screening of Alternatives", Task Report for Task 3-4.7, Oakland, California (1978).

14. Lynn, W. R., et al, "Systems Analysis for Planning Wastewater Treatment Plants", Jour. Water Poll. Control Fed., 34, 565 (1962).

15. Evenson, D. E., et al., "Preliminary Selection of Waste Treatment Systems", Jour. Water Poll. Control Fed., 41, 1845 (1969).

16. Shin, C. S. and Krishnan, P., "Dynamic Optimization for Industrial Waste Treatment Design", Jour. Water Poll. Control., 41, 1787 (1969).

17. Shih, C. S. and DeFilippi, J. A., "System Optimization of Waste Treatment Plant Process Design", Jour. San. Eng. Div., Proc. Amer. Soc. Civil Engr., 96, 402 (1970).

18. Ecker, J. G. and McNamara, J. R., "Geometric Programming and the Preliminary Design of Industrial Waste Treatment Plants", Waste Res. Research, 7, 18 (1971).

19. Berthouex, P. M. and Polkowski, L. B., "Optimum Waste Treatment Plant Design Under Uncertainty", Jour. Water Poll. Control Fed., 42, 1589 (1970).

20. Mishra, P. N., et al., "Biological Wastewater Treatment System Design, Part I. Optimal Synthesis", Canad. Jour. of Chem. Engrg., 51 694 (1973).

21. CIRIA, "Cost-Effective Sewage Treatment - The Creation of an Optimizing Model", CIRIA Report 46, Construction Industry Research and Information Association, London, Gt. Brit. (1973).

22. Bowden, K., et al., "Evaluation of the CIRIA Prototype Model for the Design of Sewage-Treatment Works", Wat. Pollut. Control, 75 192 (1976).

23. U.S. Army Corp of Engineers, "Computer Assisted Procedure for the Design and Evaluation of Wastewater Treatment Systems (CAPDET)", Draft Report, Office of the Chief of Engineers, Corps of Engineers, Department of the Army (1976).

24. Patterson, K. E., "Dynamic Programming Approach to Cost-Effective Waste-Water Treatment Alternative Selection", presented at 49th Annual Conference, Water Poll. Control Fed., Minneapolis, Minnesota, October 3-8, (1976).

25. Dick, R. I. and Simmons, D. L., "Optimal Integration of Processes for Sludge Management", Proc. of the Third National Conf. on Sludge Management Disposal and Utilization, Miami Beach, Florida, December 14-16, (1976).

26. Adams, B. J. and Panagiotakopoulos, D., "Network Approach to Optimal Wastewater Treatment System Design", Jour. Water Poll. Control Fed., 49, 623 (1977).

27. Keeney, R. L. and Raiffa, H., "Decisions With Multiple Objectives: Preferences and Value Tradeoffs", John Wiley and Sons, New York (1976).

APPENDIX A

MATHEMATICAL DEVELOPMENT OF THE SYSTEM SYNTHESIS MODEL

To simplify the notation we consider a system consisting of one wastewater treatment train and one sludge treatment train with the sidestreams from sludge treatment returned to the head of the plant. The total number of treatment stages in the system is N where the first L of these belong to the wastewater treatment train.

Each waste stream is characterized by its volumetric flow rate and the mass flow rates of a number of pollutants of interest (e.g., suspended BOD, dissolved BOD, total suspended solids, volatile suspended solids, various forms of nitrogen, etc.). In general, these streams could also be described by such physical characteristics as temperature, viscosity, specific resistance, etc. Let each stream contain M components with x_{im} the flow rate of component m influent to stage i and s_{im} the flow rate of component m in the sidestream generated at stage i. Denote the vector representations of these waste flows at stage i as X_i and S_i, respectively.

To once again simplify the notation, assume that each stage has J alternative process units available for selection. Let z_{ij} be a decision variable whose value is 1 if unit j is chosen at stage i and is 0 otherwise. Also let f_{ij} and g_{ij} be vector valued functions that describe how the influent waste stream to stage i (X_i) is transformed into an effluent stream (X_{i+1}) and a sidestream (S_i), respectively, when unit j is chosen. These functions will take into account the type of unit employed, its design specifications, and the nature of the influent waste stream. No restriction is placed on their level of complexity.

To complete the mathematical specification of the problem, assume that K different design criteria must be satisfied. In order to formulate a meaningful optimization model, assume that one of these is stated as an objective to be minimized (e.g., total cost) and all others have target values b_k that must not be exceeded. Alternatively, two or more of the criteria could be combined into a single objective function by forming a weighted sum. Let c_{ijk} be the contribution to criterion k by choosing process unit j at stage i. The same remarks made for the functions f_{ij} and g_{ij} apply to c_{ijk}. In addition, it is assumed that the c_{ijk} are positive and non-decreasing with respect to the waste stream components x_{im}.

The system design problem can now be written in the following form:

$$\text{Minimize } v_1 = \sum_{i=1}^{N} \sum_{j=1}^{J} z_{ij} \, c_{ij1} (X_i) \qquad (1)$$

$$\text{subject to } v_k = \sum_{i=1}^{N} \sum_{j=1}^{J} z_{ij} \, c_{ijk} (X_i) \leq b_k \qquad k = 2,\ldots,K \qquad (2)$$

$$X_{i+1} = \sum_{j=1}^{J} z_{ij} \, f_{ij} (X_i) \qquad i = 1,\ldots,N \qquad (3)$$

$$S_i = \sum_{j=1}^{J} z_{ij} \, g_{ij} (X_i) \qquad i = 1,\ldots N \qquad (4)$$

$$\sum_{j=1}^{J} z_{ij} = 1 \qquad i = 1,\ldots,N \qquad (5)$$

$$z_{ij} = 0 \text{ or } 1 \qquad \begin{array}{l} i = 1,\ldots,N \\ j = 1,\ldots,J \end{array} \qquad (6)$$

$$X_{L+1} = \sum_{i=1}^{L} S_i \qquad (7)$$

$$X_1 = X_o + \sum_{i=L+1}^{N} S_i \qquad (8)$$

where v_k is the value of criterion k and X_o is the plant influent waste stream vector.

Equations (1) and (2) represent the design criteria, (3) and (4) express the stagewise transformation of influent waste flows and the generation of sidestreams, while (5) and (6) insure that only one process unit is chosen at each stage. Equation (7) expresses the influent to the sludge treatment train as the sum of the sludge sidestreams generated in the wastewater treatment train. Finally, equation (8) closes the loop by adding the sludge treatment sidestreams to the plant influent.

Explicit constraints on effluent discharges from the system need not appear in the formulation since they can be satisfied by careful specification of the unit process alternatives. For example, the process waste stream transformation functions f_{ij} can be chosen so that effluent concentration is the fixed design parameter rather than such quantities as percent removal or size of the unit.

The above model is a nonlinear integer programming problem with decision variables z_{ij} and state variables x_{im} and s_{im}. Considerable difficulty is caused by the presence of the recycle equation (8). Removal of this relation would make the waste stream vector entering stage i dependent only on the process units chosen at stages 1 through i-1 and results in a much simpler problem. Suppose that equation (8) is ignored and instead a penalty is attached to each component of the sidestreams generated by sludge treatment. Let the penalty p_{km} be the increase in criterion k per unit increase in component m of the recycle stream. A method for computing these penalties is given below. Now replace the original optimization problem with a penalty-augmented one wherein equation (8) is dropped and penalty terms are added to equations (1) and (2) to give the following revised system criterion values:

$$v_k' = v_k + \sum_{i=L+1}^{N} \sum_{m=1}^{M} p_{km} \, s_{im} \qquad (9)$$

An efficient implicit enumeration technique is available to solve this new penalty-augmented problem [A1]. It makes use of the following bounding property. Suppose that a feasible system design $\bar{z}_{ij}$ with criterion values $\bar{v}_k'$ has been found. If at stage q a different process r is proposed and

$$\sum_{i=1}^{q-1} \sum_{j=1}^{J} \bar{z}_{ij} \, c_{ijk} + c_{qrk} > \begin{cases} \bar{v}_1' & \text{for } k=1 \qquad (10a) \\ & \text{or} \\ b_k & \text{for any } k \neq 1 \qquad (10b) \end{cases}$$

then process r and all combination of process units beyond stage q can be excluded from consideration. (Note that penalty terms should be added to expression (10) if q > L.). This type of result can considerably reduce the number of unit process combinations that need to be evaluated. A systematic procedure for using this property to identify the optimal values of the z_{ij} is given in Figure A1.

The problem remains of establishing representative values for the penalties for sludge treatment recycle streams. Since these values will depend on the choice of process units, which are unknowns, a heuristic,

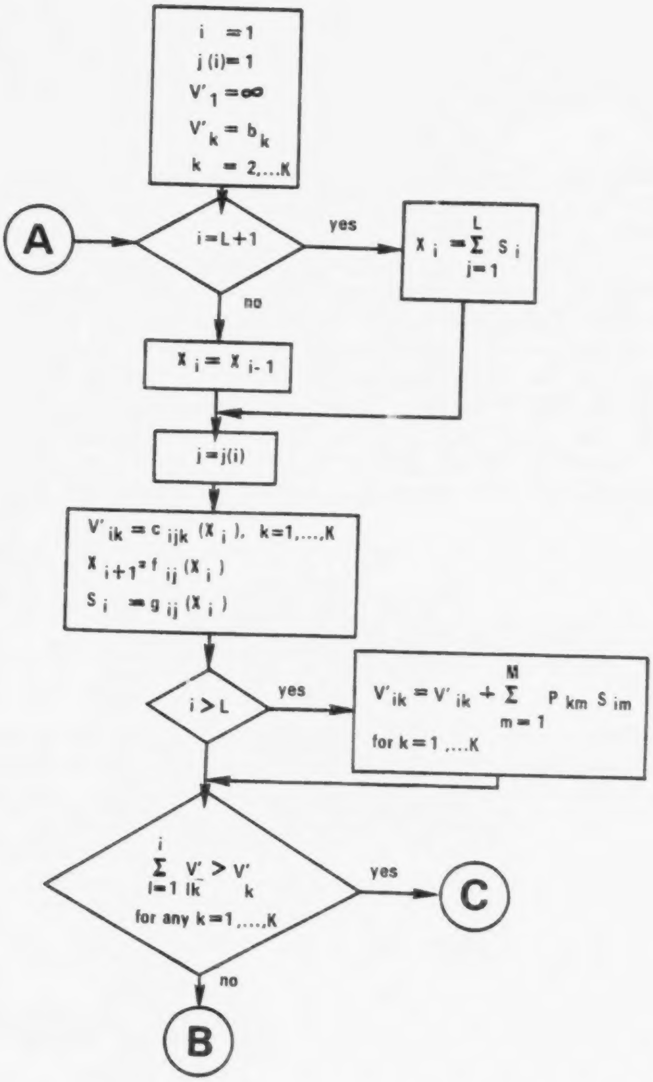
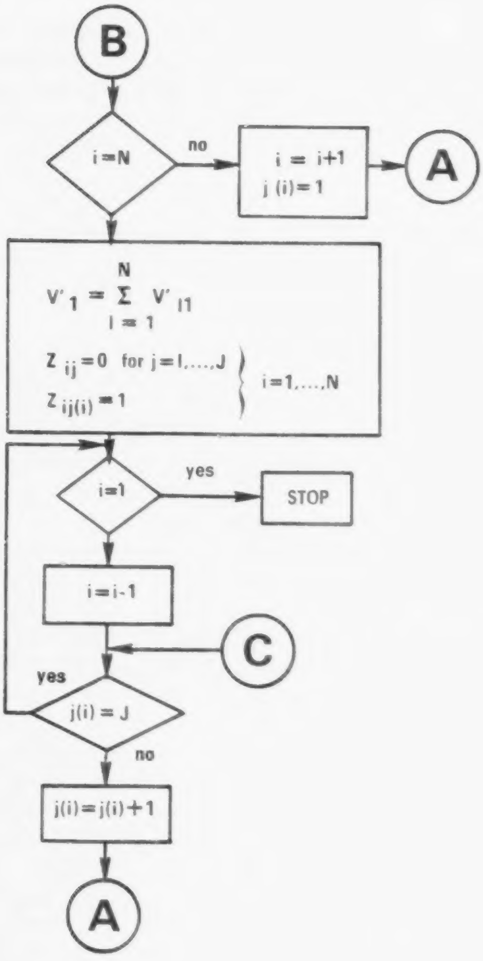

i = 1
j (i) = 1
V'1 = ∞
V'k = bk
k = 2,...K
A
i = L + 1
yes
no
X i = Σ S i
L
j = 1
X i = X i-1
j = j(i)
V'ik = c ijk (X i), k = 1,...,K
X i+1 = f ij (X i)
S i = g ij (X i)
i > L
yes
V'ik = V'ik + Σ P km S im
M
m = 1
for k = 1,...K
Σ V'lk > V'k
i
l = 1
for any k = 1,...,K
yes
C
no
B

Figure A1. Flow chart of the implicit enumeration procedure

(continued)



B
i = N
no
i = i+1
j (i) = 1
A
$V'_1 = \sum_{l=1}^{N} V'_{l1}$
$Z_{ij} = 0$ for $j = 1, \ldots, J$
$Z_{ij(i)} = 1$
$i = 1, \ldots, N$
yes
i = 1
STOP
i = i-1
C
yes
j(i) = J
no
j(i) = j(i)+1
A

Figure A1. (continued)

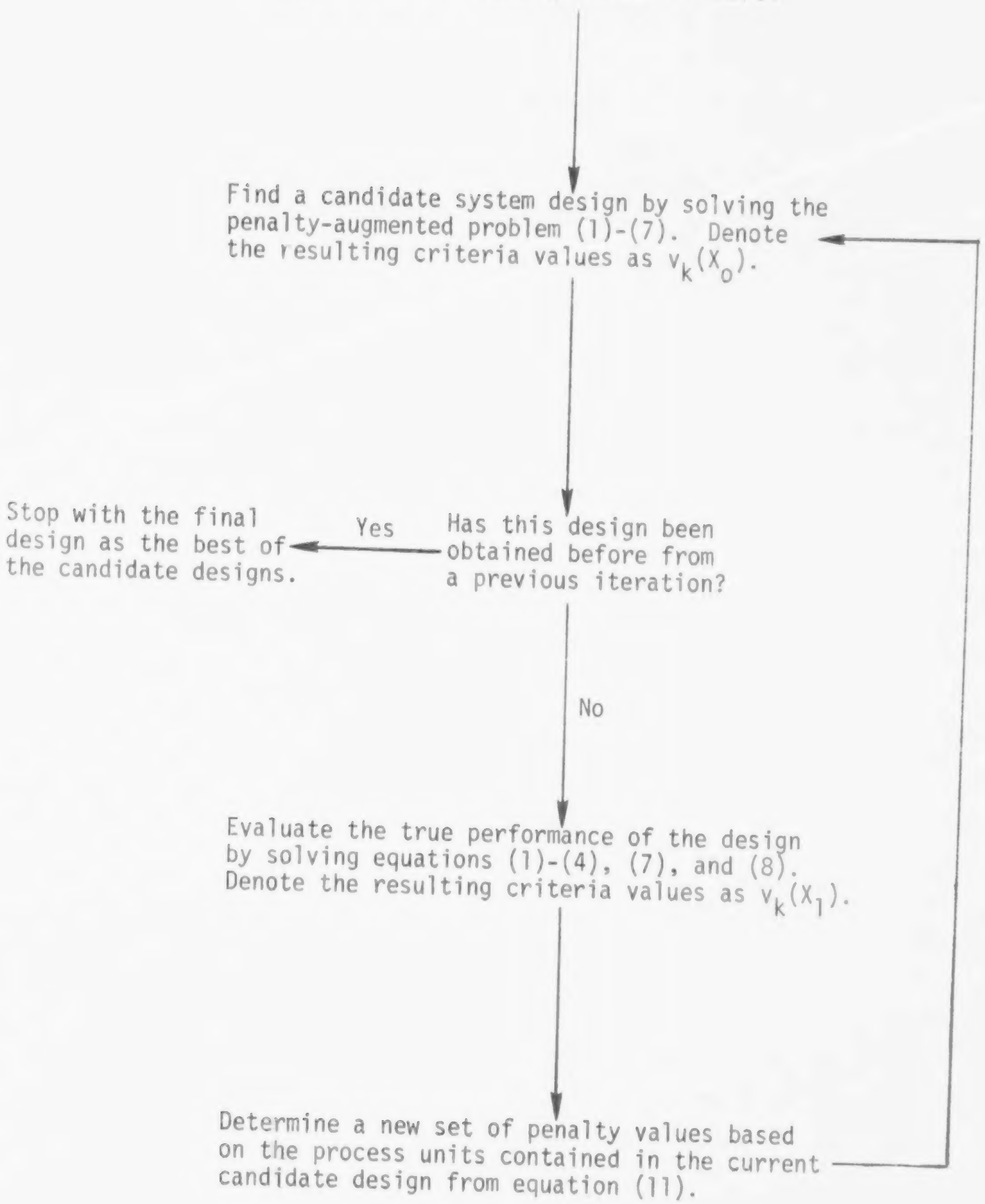
iterative approach that successively generates new system designs and corresponding penalty values is employed. It is described in the flowchart of Figure A2.

After each iteration has identified a new candidate design, the criterion values with and without the sludge treatment recycle stream ($v_k(X_1)$ and $v_k(X_o)$, respectively) for this design are computed. Then new penalty values can be found from

$$p_{km} = \left[\frac{(\Delta v_k)_m}{(\Delta X_o)_m}\right] \left[\frac{v_k(X_1) - v_k(X_o)}{\sum_{\ell=1}^{M} (\Delta v_k)_\ell}\right] , \quad (11)$$

where $(\Delta v_k)_m$ is the change in $v_k(X_o)$ when a quantity $(\Delta X_o)_m$ is added to the m-th component of the plant influent. The $(\Delta v_k)_m$ are evaluated numerically by solution of equations (1)-(4) and (7) as X_o is pertubed by an amount $(\Delta X_o)_m$ under the current candidate system design. The first term in brackets is a numerical approximation to the partial derivative of criterion k with respect to system recycle component m. The second term is an adjustment factor that allows $v_k(X_1)$ to satisfy a first order Taylor series expansion about $v_k(X_o)$.

Very often a designer would be interested in identifying the system designs that are within α percent of least-cost (or least-energy, etc.). The solution procedure previously described can easily be extended to provide such information. After the best candidate design is identified, its corresponding penalty values are used once again in solving the penalty-augmented problem. Only this time the right hand side of the bounding relation (10a) is multiplied by $(1+\alpha/100)$. Each complete system design generated during the course of the implicit enumeration algorithm that is within α percent of the best design is saved. Its true performance is later evaluated by solving equations (1)-(4), (7) and (8).



Begin with all penalty values at zero.

Find a candidate system design by solving the penalty-augmented problem (1)-(7). Denote the resulting criteria values as $v_k(X_o)$.

Has this design been obtained before from a previous iteration?

Stop with the final design as the best of the candidate designs.

Evaluate the true performance of the design by solving equations (1)-(4), (7), and (8). Denote the resulting criteria values as $v_k(X_1)$.

Determine a new set of penalty values based on the process units contained in the current candidate design from equation (11).

Figure A2. Overall system design algorithm

REFERENCES

A1. Rodrigo, B., F. R. and Seader, J. D., "Synthesis of Separation Sequences by Ordered Branch Search", AIChE Jour., 21, 885 (1975).

APPENDIX B

EXEC/OP USERS' GUIDE

As a preliminary step to using the EXEC/OP computer program it is suggested that the user first prepare a multi-option flow diagram of the waste treatment system. An example of such a diagram for a hypothetical design problem is shown in Figure B1. The following simple rules must be followed in preparing these diagrams:

(1) Treatment stages are numbered in order, starting with those in the wastewater treatment train, followed by those in the secondary sludge train, and then by those in the primary/mixed sludge treatment train.

(2) There must be at least one stage in each of the three treatment trains. If the possibility of separate treatment of primary and secondary sludges is not to be considered then the user can simply use a single stage with the "null process" as its only option in the secondary sludge train.

(3) The unit process options selected for consideration at each stage must be from those listed in Table B1. The same type of process can be used at several different design levels and at several different stages in the system.

(4) The sidestreams from sludge processing can be assigned to any wastewater treatment stage except the first stage.

Once a multi-option flow diagram has been prepared, EXEC/OP can be used to select the process option at each stage of the system that will best meet a set of design criteria. These criteria are listed in Table B2. They can be combined together in a weighted objective function whose value is to be minimized and they can have constraint levels associated with them whose values are not be be violated by any feasible design.

Figure B2 shows the general organization of the input data to EXEC/OP. A brief description of each category of input along with its FORTRAN format now follows:

Title Card - contains a descriptive title for the problem (40A2).

Influent Waste Cards - gives the values of the influent waste parameters listed in Table B3 (8F10.0).

Effluent Standards Card - gives the required effluent standards for 5-day BOD, suspended solids, ammonia nitrogen, nitrate nitrogen and phosphorus in mg/l, (5F10.0).

Economic Parameter Cards - gives values for the economic parameters listed in Table B4 (8F10.0).

System Structure Card - lists the number of stages in the wastewater treatment, secondary sludge, and primary sludge trains, respectively, the total number of process options considered, and the stage where sidestreams from sludge processing are returned for treatment (5I10).

Sludge Assignment Card - gives the stage where the sludge from each wastewater treatment stage is sent (must be the first stage of either the primary or secondary sludge trains) (8I10).

Process Design Data Cards - at least four cards for every process option (except the "null process"):

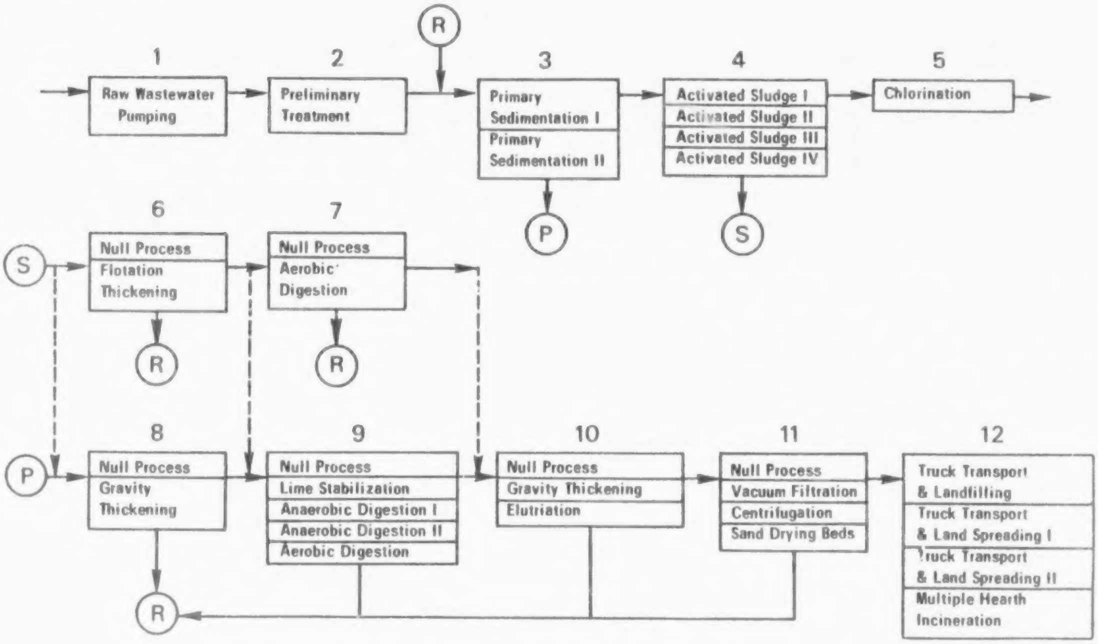

R
1
Raw Wastewater Pumping
2
Preliminary Treatment
3
Primary Sedimentation I
Primary Sedimentation II
4
Activated Sludge I
Activated Sludge II
Activated Sludge III
Activated Sludge IV
5
Chlorination
P
S
6
S
Null Process
Flotation Thickening
R
7
Null Process
Aerobic Digestion
R
8
P
Null Process
Gravity Thickening
9
Null Process
Lime Stabilization
Anaerobic Digestion I
Anaerobic Digestion II
Aerobic Digestion
10
Null Process
Gravity Thickening
Elutriation
11
Null Process
Vacuum Filtration
Centrifugation
Sand Drying Beds
12
Truck Transport & Landfilling
Truck Transport & Land Spreading I
Truck Transport & Land Spreading II
Multiple Hearth Incineration
R

Figure B1. Multi-option flow diagram for a hypothetical design problem

TABLE B1. EXEC/OP UNIT PROCESSES

Process	Subroutine ID Number
Null Process	0
Preliminary Treatment	1
Primary Sedimentation	2
Activated Sludge (Aeration Basin and Final Settler)	3
Anaerobic Digestion	6
Vacuum Filtration	7
Gravity Thickening	8
Elutriation	9
Sand Drying Beds	10
Trickling Filter - Final Settler	11
Chlorination - Dechlorination	12
Flotation Thickening	13
Multiple Hearth Incineration	14
Raw Wastewater Pumping	15
Sludge Holding Tanks	16
Centrifugation	17
Aerobic Digestion	18
Truck Transport/Land Disposal of Sludge (Land Spreading or Landfilling)	22
Lime Stabilization	23
Rotating Biological Contactor - Final Settler	24
Primary Sedimentation - Activated Sludge - Waste Activated Sludge Returned to Primary Clarifie	25
Nonoxidative Heat Treatment	26

TABLE B2. EXEC/OP DESIGN CRITERIA

1. Initial Construction Cost, million $
2. Annual Operation and Maintenance Cost, $/mil. gal.
3. Total Equivalent Annual Cost, $/mil. gal.
4. Gross Energy Consumption, kwh/mil. gal.
5. Gross Energy Production, kwh/mil. gal.
6. Net Energy Consumption, kwh/mil. gal.
7. Land Utilization, acres.
8. Undesireability Index.

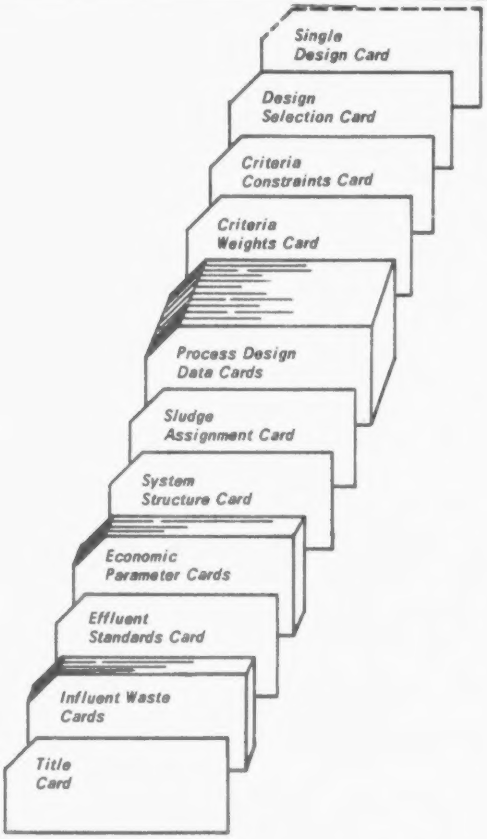

Single Design Card
Design Selection Card
Criteria Constraints Card
Criteria Weights Card
Process Design Data Cards
Sludge Assignment Card
System Structure Card
Economic Parameter Cards
Effluent Standards Card
Influent Waste Cards
Title Card

Figure B2. Organization of input data for EXEC/OP

TABLE B3. EXEC/OP WASTE STREAM PARAMETERS

Q	Volumetric Flow, mgd
SOC	Suspended Organic Carbon, mg/l
SNBC	Suspended Nonbiodegradable Carbon, mg/l
SON	Suspended Organic Nitrogen, mg/l
SOP	Suspended Organic Phosphorus, mg/l
SFM	Suspended Fixed Matter, mg/l
SBOD	Suspended 5-Day BOD, mg/l
VSS	Volatile Suspended Solids, mg/l
TSS	Total Suspended Solids, mg/l
DOC	Dissolved Organic Carbon, mg/l
DNBC	Dissolved Nonbiodegradable Carbon, mg/l
DN	Dissolved Nitrogen, mg/l
DP	Dissolved Phosphorus, mg/l
DFM	Dissolved Fixed Matter, mg/l
ALK	Alkalinity, mg/l
DBOD	Dissolved 5-Day BOD, mg/l
NH3	Ammonia Nitrogen, mg/l
NO3	Nitrate Nitrogen, mg/l

TABLE B4. EXEC/OP ECONOMIC PARAMETERS

EPA Sewage Treatment Plant Cost Index (1957-59=1.0)
Wholesale Price Index (1957-59=1.0)
Discount Rate
Length of Planning Period, yrs.
Direct Hourly Wage, $/hr.
Fraction of Direct Hourly Wage Charged to Indirect Labor
Cost of Electricity, $/kwh
Cost Escalator for Yarkwork, Laboratories, Legal Fees, Engineering and Interest
Efficiency of Converting Heating Value of Fuels into Equivalent Electrical Energy

1-st card - tells at which stage the option appears, the identification number assigned to the process, the identification number of the process subroutine (see Table B1), the maximum energy production possible from the process (in equivalent kwh/mil. gal. of plant influent), and the undesireability rating for the process (3I10, 2F10.0).

2-nd Card - contains a descriptive title for the process (40A2).

3-rd and 4-th cards - lists the values of the 16 input design parameters for the process (see Appendix C). (8F10.0).

Additional Cards - contains any supplementary input data (see Appendix C). (8F10.0).

Criteria Weight Card - lists the weights attached to each selection criterion of Table B2 (8F10.0).

Criteria Constraint Card - gives the upper allowable limit (lower limit for energy production) for each selection criterion of Table B2 (8F10.0).

Design Selection Card - gives the values of M and X where the user desires to identify the M best designs that are within 100X% of one another (with respect to the weighted objective function). (I10, F10.0).

Single Design Card - lists the identification number of the process option to be selected at each stage of the system (used only when no optimization is to be performed and the user desires detailed performance data for a particular system design) (8I10).

Appendix C provides a description of the input parameters needed for each type of unit process. A sample input deck for the flow diagram of Figure B1 is shown in Figure B3. The DEC PDP-11/70 computer on which this problem was run allows a data field to be terminated by a comma and two successive commas indicates a value of 0. Thus the input data appearing in Figure B3 does not line up in field widths of 10 spaces each. The last three lines of this data indicate that the design problem involves total cost minimization, that no constraints are placed on the design criteria (values of the constraint limits are set to very high numbers or zero for energy production), and that the five best designs whose costs are within 5 percent of one another is desired.

The resulting EXEC/OP output for this example is shown in Figure B4. The first three tables present summaries of the input data. The section titled "Optimization Phase" lists the designs arrived at while searching for the first-best solution. The "Sensitivity Phase" section gives the five top designs with respect to total cost. Each design listing in these sections indicates the process option used at each stage of the system (stages using the "null process" are skipped), the amount of sludge either generated or handled, and the values of the eight system selection criteria. The stage where mixing of primary and secondary sludges occurs is shown with an asterisk. At the end of the output is shown how efficient the search method of EXEC/OP was in comparison to a complete enumeration of all possible system configurations. (Note: the total number of possible system configurations equals the product of the number of process options considered at each stage. This number is 15,360 for the system in this sample problem).

The user is advised that because of the heuristic nature of the optimization method used in EXEC/OP, the "best" design arrived at in the "Optimization Phase" may be close to but not equal to the true optimum. In such cases one of the M next-best designs listed in the "Sensitivity Phase" results may have a better objective function value. Thus the use of the M next-best design feature provides added insurance that the true mathematical optimum. is not missed in addition to its other useful informational properties.

Should the user desire a detailed performance evaluation of any particular design configuration of the multi-option flow diagram, the single design evaluation feature of EXEC/OP can be used. For example, assume that this kind of information is requested for the least-cost design in our sample

```
                                   CASE STUDY 1
10., 105., 30., 10., 2., 30., 140., 229.
254., 43., 11., 19., 4., 500., 250., 60.
15., 0.
30., 30., 10000., 10000., 10000.
2.88, 2., .06375, 20., 5.91, .15, .033, 1.33
.31
5, 2, 5, 31, 3
8, 8, 8, 6, 6
1,1,15, 0., 0.
RAW WASTEWATER PUMPING
30., , , , , , , ,
, , , , , , , 1.
2,2,1, 0., 0.
PRELIMINARY TREATMENT
1., , , , , , , ,
, , , , , , , 1.
3,3,2, 0., 0.
PRIMARY SEDIMENTATION (40% SOLIDS REMOVAL)
.4, 200., 14., , , , , ,
, , , , , , 1., 1.
3,4,2, 0., 0.
                          (60% SOLIDS REMOVAL)
.6, 200., 14., , , , , ,
, , , , , , 1., 1.
4,5,3, 0., 0.
ACTIVATED SLUDGE (MLVSS=2000, R=.3)
30., 30., 2000., .3, 200., .5, 10., .48
7., .05, 800., 30., 1., 1., 1., 1.
4,6,3, 0., 0.
                 (MLVSS=2000, R=.5)
30., 30., 2000., .5, 200., .5, 10., .48
7., .05, 800., 30., 1., 1., 1., 1.
4,7,3, 0., 0.
                 (MLVSS=3000, R=.3)
30., 30., 3000., .3, 200., .5, 10., .48
7., .05, 800., 30., 1., 1., 1., 1.
4,8,3, 0., 0.
                 (MLVSS=3000, R=.5)
30., 30., 3000., .5, 200., .5, 10., .48
7., .05, 800., 30., 1., 1., 1., 1.
5,9,12, 0., 0.
CHLORINATION (8 MG/L DOSAGE)
8., 30., 220., 2.5, 180., , , ,
, , , , , 1., 1., 1.
6,30,0, 0., 0.
NULL PROCESS
6,10,13, 0., 0.
```

Figure B3. Input data for hypotetical design problem

```
AIR FLOTATION THICKENING (TO 4% SOLIDS)
.95, 40000., 1150., 48., 96., 10., .45, 0.
, , , , , , , 1.
7,30,0, 0., 0.
NULL PROCESS
7,11,18, 0., 0.
AEROBIC DIGESTION (10 DAYS)
0., 0., 0., 20., 10., .48, .5, 0.
0., 7., .05, 0., 0., 0., 1., 1.
8,30,0, 0., 0.
NULL PROCESS
8,12,8, 0., 0.
GRAVITY THICKENING (TO 8% FOR PPT, 5% FOR MIXED SLUDGE)
.9, 0., 700., 0., 80000., 20000., 50000., 16.
6., 8., , , , , , 1.
9,30,0, 0., 0.
NULL PROCESS
9,13,23, 0., 0.
LIME STABILIZATION (200 LBS/TON)
200., 25., , , , , , ,
, , , , , , , 1.
9,14,6, 2000., 0.
ANAEROBIC DIGESTION (15 DAYS)
15., 30., .5, .31, , , , ,
, , , , , , , 1.
9,15,6, 2000., 0.
                    (20 DAYS)
20., 30., .5, .31, , , , ,
, , , , , , , 1.
9,16,18, 0., 0.
AEROBIC DIGESTION (20 DAYS)
0., 0., 0., 20., 20., .48, .5, 0.
0., 7., .05, 0., 0., 0., 1., 1.
10,17,8, 0., 0.
GRAVITY THICKENING (TO 5% SOLIDS)
.9, 0., 700., 0., 80000., 20000., 50000., 16.
6., 8., , , , , , 1.
10,18,9, 0., 0.
ELUTRIATION (WASHWATER RATIO = 3, THICKENS TO 4%)
.76, 0., 3., 800., 0., 60000., 20000., 40000.
16., 6., 8., , , , , 1.
10,30,0, 0., 0.
NULL PROCESS
11,19,7, 0., 0.
```

Figure B3. (continued)

```
VACUUM FILTRATION (10 GPH/SQ FT)
0., 35., 2000., 0., 0., 0., .064, .0125
0., .33, 1., , , , , 1.
10., 10., 10., 10., 10., 10., 10., 10.
10., 10., 10., 10., 10., 10., 10.
42., 0., 52., 42., 0., 40., 76., 0.
110., 68., 0., 125., 0., 0., 0.
176., 0., 200., 0., 0., 0., 240., 0.
370., , , , , , ,
, , , , , , , ,
, , , , , , ,
11,20,17, 0., 0.
CENTRIFUGATION
0., 0., 35., 0., 0., 2., 0., 2.
1., , , , , , , 1.
.9, .85, .9, .9, .85, .9, .9, .85
.85, .9, .85, .85, 0., 0., 0.
32., 10., 19., 30., 18., 30., 25., 15.
22., 25., 15., 22., 0., 0., 0.
3., 6., 6., 3., 4., 4., 2., 4.
4., 2., 4., 4., 0., 0., 0.
90., 80., 80., 160., 160., 160., 100., 80.
80., 100., 80., 80., 100., 80., 80.
11,21,10, 0., 0.
SAND DRYING BEDS (30% CAKE SOLIDS)
0., 2000., .3, .3, .3, 15., 1., 3000.
, , , , , , , 1.
11,30,0, 0., 0.
NULL PROCESS
12,22,22, 0., 0.
LAND SPREADING (10 MILE HAUL, 3000 $/AC, 400 LB N/AC/YR)
2160., 10., 6., .5, 3000., 0., .25, 400.
500., 10., 0., 0., 0., 0., 1., 1.
12,23,22, 0., 0.
                   (30 MILE HAUL, 2000 $/AC, 600 LB N/AC/YR)
2160., 30., 6., .5, 2000., 0., .25, 600.
500., 10., 0., 0., 0., 0., 1., 1.
12,24,22, 0., 0.
LANDFILLING (10 MILE HAUL, 3000 $/AC)
2160., 10., 6., .5, 3000., 1., 0., 0.
, , , , , , 1., 1.
12,25,14, 0., 0.
INCINERATION (2 LB/HP/SQ FT)
2., 2., 35., 5., 0., 10000., 1., .3
1., , , , , , , 1.
0., 0., 1., 0., 0., 0., 0., 0.
10000., 10000., 10000., 10000., 0., 10000., 10000., 10000.
5, .05
```

Figure B3. (continued)

```
                              EXECUTIVE PROGRAM
                            (OPTIMIZATION VERSION)
                                     FOR
                PRELIMINARY SYNTHESIS OF WASTE TREATMENT SYSTEMS

                       U.S. ENVIRONMENTAL PROTECTION AGENCY
                   MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
                      SYSTEMS AND ECONOMIC ANALYSIS SECTION
                             CINCINNATI, OHIO 45268

                                CASE STUDY 1

                              PROCESS ALTERNATIVES
                              --------------------

OPTION  PROCESS  STAGE  SIDESTREAM                              REMARKS
  NO.     NO.     NO.   DESTINATION
------  -------  -----  -----------  ------------------------------------------------------------------
   1      15       1        8        RAW WASTEWATER PUMPING
   2       1       2        8        PRELIMINARY TREATMENT
   3       2       3        8        PRIMARY SEDIMENTATION (40% SOLIDS REMOVAL)
   4       2       3        6                              (60% SOLIDS REMOVAL)
   5       3       4        6        ACTIVATED SLUDGE (MLVSS=2000, R=.3)
   6       3       4        6                         (MLVSS=2000, R=.5)
   7       3       4        6                         (MLVSS=3000, R=.3)
   8       3       4        6                         (MLVSS=3000, R=.5)
   9      12       5        6        CHLORINATION (8 MG/L DOSAGE)
  30       0       6        3        NULL PROCESS
  10      13       6        3        AIR FLOTATION THICKENING (TO 4% SOLIDS)
  30       0       7        3        NULL PROCESS
  11      18       7        3        AEROBIC DIGESTION (10 DAYS)
  30       0       8        3        NULL PROCESS
  12       8       8        3        GRAVITY THICKENING (TO 8% FOR PRI, 5% FOR MIXED SLUDGE)
  30       0       9        3        NULL PROCESS
  13      23       9        3        LIME STABILIZATION (200 LBS/TON)
  14       6       9        3        ANAEROBIC DIGESTION (15 DAYS)
  15       6       9        3                            (20 DAYS)
  16      18       9        3        AEROBIC DIGESTION (20 DAYS)
  17       8      10        3        GRAVITY THICKENING (TO 5% SOLIDS)
  18       9      10        3        ELUTRIATION (WASHWATER RATIO = 3, THICKENS TO 4%)
  30       0      10        3        NULL PROCESS
  19       7      11        3        VACUUM FILTRATION (10 GPH/SQ FT)
  20      17      11        3        CENTRIFUGATION
  21      10      11        3        SAND DRYING BEDS (30% CAKE SOLIDS)
  30       0      11        3        NULL PROCESS
  22      22      12        3        LAND SPREADING (10 MILE HAUL, 3000 $/AC, 400 LB N/AC/YR)
  23      22      12        3                       (30 MILE HAUL, 2000 $/AC, 600 LB N/AC/YR)
  24      22      12        3        LANDFILLING (10 MILE HAUL, 3000 $/AC)
  25      14      12        3        INCINERATION (2 LB/HR/SQ FT)
```

Figure B4. EXEC/OP output for hypothetical design problem

```
                      SELECTION CRITERIA
                      ------------------

     CRITERION                            WEIGHT         LIMIT
     ---------                            ------         -----

 1.  INITIAL CONSTR. COST, M$              0.00        10000.00
 2.  ANNUAL O & M COST, $/MG               0.00        10000.00
 3.  TOTAL ANNUAL COST, $/MG               1.00        10000.00
 4.  ENERGY CONSUMED, KWH/MG               0.00        10000.00
 5.  ENERGY PRODUCED, KWH/MG               0.00            0.00
 6.  NET ENERGY CONSUMED, KWH/MG           0.00        10000.00
 7.  LAND REQUIRED, ACRES                  0.00        10000.00
 8.  UNDESIRABILITY INDEX                  0.00        10000.00


                        ECONOMIC DATA
                        -------------

       CONSTRUCTION COST INDEX                     2.8800
       WHOLESALE PRICE INDEX                       2.0000
       DIRECT HOURLY WAGE, $/HR                    5.9100
       FRACTION CHARGED TO SUPERVISION             0.1500
       COST ESCALATOR FOR MISC. FEES               1.3300
       COST OF ELECTRICITY, $/KWH                  0.0330
       FUEL CONVERSION EFFICIENCY                  0.3100
       DISCOUNT RATE                               0.0637
       CAPITAL RECOVERY FACTOR                     0.0899
```

Figure B4. (continued)

```
                                   OPTIMIZATION PHASE
                                   ------------------


                                      DESIGN   1
                                      ---------

                           EXACT SYSTEM VALUE          291,128
                           APPROX. SYSTEM VALUE        259,484
                           PENALTY FROM RECYCLES         0,000

STAGE  PROCESS  SLUDGE,                                    SELECTION CRITERIA
 NO.   OPTION   TONS/DAY         1         2         3         4         5         6         7         8
-----  -------  --------     --------  --------  --------  --------  --------  --------  --------  --------
  1       1        0,00          0,91     10,09     32,39    141,37      0,00    141,37      0,00      0,00
  2       2        0,00          0,28      9,36     16,15      5,22      0,00      5,22      0,00      0,00
  3       4        7,65          0,59     12,45     27,07      8,78      0,00      8,78      0,00      0,00
  4       7        2,16          1,54     48,22     86,06    648,00      0,00    648,00      0,00      0,00
  5       9        0,00          0,29     17,68     24,85    121,80      0,00    121,80      0,00      0,00
  8*     12        9,81          0,16      2,19      6,13      1,85      0,00      1,85      0,00      0,00
  9      14        8,83          0,55      5,64     19,06    226,99    411.16   -184,16      0,00      0,00
 10      18        4,90          0,11      1,64      4,47      1,28      0,00      1.28      0,00      0,00
 12      22        3,72          0,91     42,43     74,95     78,75      0,00     78,75    284,35      0,00
                --------     --------  --------  --------  --------  --------  --------  --------  --------
SYSTEM VALUES      9,81          5,33    149.70    291,13   1234,04    411.16    822,89    284,35      0,00

                                      DESIGN   2
                                      ---------

                           EXACT SYSTEM VALUE          276,155
                           APPROX. SYSTEM VALUE        280,542
                           PENALTY FROM RECYCLES        12,321

STAGE  PROCESS  SLUDGE,                                    SELECTION CRITERIA
 NO.   OPTION   TONS/DAY         1         2         3         4         5         6         7         8
-----  -------  --------     --------  --------  --------  --------  --------  --------  --------  --------
  1       1        0,00          0,91     10,09     32,39    141,37      0,00    141,37      0,00      0,00
  2       2        0,00          0,28      9,36     16,15      5,22      0,00      5,22      0,00      0,00
  3       4        6,71          0,59     12,37     26,89      8,71      0,00      8,71      0,00      0,00
  4       7        1,70          1,49     47,22     84,02    630,17      0,00    630,17      0,00      0,00
  5       9        0,00          0,29     17,52     24,65    120,53      0,00    120,53      0,00      0,00
  9*     14        8,41          0,64      6,52     22,35    299,38    418,92   -119,54      0,00      0,00
 10      17        4,39          0,11      1,57      4,27      1,21      0,00      1,21      0,00      0,00
 11      21        3,95          0,42     20,32     30,70      0,86      0,00      0,86      1,35      0,00
 12      25        3,95          0,88     12,99     34,73     99,67      0,00     99,67      0,00      0,00
                --------     --------  --------  --------  --------  --------  --------  --------  --------
SYSTEM VALUES      8,41          5,61    137,98    276,15   1307,13    418,92    888,21      1,35      0,00
```

Figure B4. (continued)

```
                                        DESIGN   3
                                        ---------

                                EXACT SYSTEM VALUE          276,155
                                APPROX. SYSTEM VALUE        276,155
                                PENALTY FROM RECYCLES         7,934

                                   SAME SYSTEM AS DESIGN   2


                                     SENSITIVITY PHASE
                                     -----------------


                                        DESIGN   1
                                        ---------

                                EXACT SYSTEM VALUE          276,155

STAGE  PROCESS  SLUDGE,                                          SELECTION CRITERIA
 NO.   OPTION   TONS/DAY        1          2          3          4          5          6          7          8
-----  -------  ---------  ---------  ---------  ---------  ---------  ---------  ---------  ---------  ---------
  1       1          0.00       0.91      10.09      32.39     141.37       0.00     141.37       0.00       0.00
  2       2          0.00       0.28       9.36      16.15       5.22       0.00       5.22       0.00       0.00
  3       4          6.71       0.59      12.37      26.89       8.71       0.00       8.71       0.00       0.00
  4       7          1.70       1.49      47.22      84.02     630.17       0.00     630.17       0.00       0.00
  5       9          0.00       0.29      17.52      24.65     120.53       0.00     120.53       0.00       0.00
  9*     14          8.41       0.64       6.52      22.35     299.38     418.92    -119.54       0.00       0.00
 10      17          4.39       0.11       1.57       4.27       1.21       0.00       1.21       0.00       0.00
 11      21          3.95       0.42      20.32      30.70       0.86       0.00       0.86       0.00       0.00
 12      25          3.95       0.88      12.99      34.73      99.67       0.00      99.67       1.35       0.00
                                                                                                 0.00       0.00
                ---------  ---------  ---------  ---------  ---------  ---------  ---------  ---------  ---------
SYSTEM VALUES        8.41       5.61     137.98     276.15    1307.13     418.92     888.21       1.35       0.00
```

Figure B4. (continued)

```
                                          DESIGN   2
                                          ---------

                                EXACT SYSTEM VALUE          279,791

STAGE  PROCESS  SLUDGE,                                       SELECTION CRITERIA
 NO,   OPTION   TONS/DAY        1         2         3         4         5         6         7         8
-----  -------  --------    --------  --------  --------  --------  --------  --------  --------  --------
  1       1        0,00         0,91     10,09     32,39    141,37      0,00    141,37      0,00      0,00
  2       2        0,00         0,28      9,36     16,15      5,22      0,00      5,22      0,00      0,00
  3       4        6,70         0,59     12,37     26,89      8,71      0,00      8,71      0,00      0,00
  4       7        1,70         1,49     47,06     83,79    627,27      0,00    627,27      0,00      0,00
  5       9        0,00         0,29     17,52     24,65    120,53      0,00    120,53      0,00      0,00
  9*     15        8,40         0,78      7,72     26,91    348,83    425,58    -76,75      0,00      0,00
 10      17        4,33         0,11      1,57      4,25      1,20      0,00      1,20      0,00      0,00
 11      21        3,90         0,42     20,06     30,32      0,85      0,00      0,85      1,33      0,00
 12      25        3,90         0,88     12,89     34,45     99,30      0,00     99,30      0,00      0,00
                --------    --------  --------  --------  --------  --------  --------  --------  --------
SYSTEM VALUES      8,40         5,73    138,64    279,79   1353,28    425,58    927,70      1,33      0,00


                                          DESIGN   3
                                          ---------

                                EXACT SYSTEM VALUE          277,631

STAGE  PROCESS  SLUDGE,                                       SELECTION CRITERIA
 NO,   OPTION   TONS/DAY        1         2         3         4         5         6         7         8
-----  -------  --------    --------  --------  --------  --------  --------  --------  --------  --------
  1       1        0,00         0,91     10,09     32,39    141,37      0,00    141,37      0,00      0,00
  2       2        0,00         0,28      9,36     16,15      5,22      0,00      5,22      0,00      0,00
  3       4        6,71         0,59     12,37     26,89      8,71      0,00      8,71      0,00      0,00
  4       7        1,70         1,49     47,22     84,02    630,17      0,00    630,17      0,00      0,00
  5       9        0,00         0,29     17,52     24,65    120,53      0,00    120,53      0,00      0,00
  9*     14        8,41         0,64      6,52     22,35    299,38    418,92   -119,54      0,00      0,00
 10      17        4,39         0,11      1,57      4,27      1,21      0,00      1,21      0,00      0,00
 11      21        3,95         0,42     20,32     30,70      0,86      0,00      0,86      1,35      0,00
 12      24        3,95         0,51     19,13     36,21     17,44      0,00     17,44     18,04      0,00
                --------    --------  --------  --------  --------  --------  --------  --------  --------
SYSTEM VALUES      8,41         5,24    144,12    277,63   1224,90    418,92    805,98     19,40      0,00
```

Figure B4. (continued)

```
                              DESIGN   4
                              ---------

                EXACT SYSTEM VALUE          277,743

STAGE  PROCESS  SLUDGE,                                          SELECTION CRITERIA
 NO,   OPTION   TONS/DAY          1         2          3          4          5          6          7          8
-----  -------  --------     --------  ---------  ---------  ---------  ---------  ---------  ---------  ---------
  1       1       0,00           0,91      10,09      32,39     141,37       0.00     141,37       0.00       0.00
  2       2       0,00           0,28       9,36      16,15       5,22       0.00       5,22       0.00       0.00
  3       4       6,60           0,59      12,36      26,86       8,70       0.00       8,70       0.00       0.00
  4       7       1,64           1,49      47,13      83,81     628,67       0.00     628,67       0.00       0.00
  5       9       0,00           0,29      17,49      24,62     120,31       0.00     120,31       0.00       0.00
  9*     14       8,24           0,64       6,45      22,10     293,88     418,12    -124,23       0.00       0.00
 10      17       4,23           0,11       1,56       4,21       1,19       0.00       1,19       0.00       0.00
 12      22       3,81           0,77      43,68      67,62      65,72       0.00      65,72     336,50       0.00
                --------     --------  ---------  ---------  ---------  ---------  ---------  ---------  ---------
SYSTEM VALUES     8,24           5,06     148,13     277,74    1265,06     418,12     846,94     336,50       0.00


                              DESIGN   5
                              ---------

                EXACT SYSTEM VALUE          281,315

STAGE  PROCESS  SLUDGE,                                          SELECTION CRITERIA
 NO,   OPTION   TONS/DAY          1         2          3          4          5          6          7          8
-----  -------  --------     --------  ---------  ---------  ---------  ---------  ---------  ---------  ---------
  1       1       0.00           0,91      10,09      32,39     141,37       0.00     141,37       0.00       0.00
  2       2       0.00           0,28       9,36      16,15       5,22       0.00       5,22       0.00       0.00
  3       4       6,70           0,59      12,37      26,89       8,71       0.00       8,71       0.00       0.00
  4       7       1,70           1,49      47,06      83,79     627,27       0.00     627,27       0.00       0.00
  5       9       0.00           0,29      17,52      24,65     120,53       0.00     120,53       0.00       0.00
  9*     15       8,40           0,78       7,72      26,91     348,83     425,58     -76,75       0.00       0.00
 10      17       4,33           0,11       1,57       4,25       1,20       0.00       1,20       0.00       0.00
 11      21       3,90           0,42      20,06      30,32       0,85       0.00       0,85       1,33       0.00
 12      24       3,90           0,50      18,97      35,97      17,28       0.00      17,28      17,78       0.00
                --------     --------  ---------  ---------  ---------  ---------  ---------  ---------  ---------
SYSTEM VALUES     8,40           5,36     144,72     281,32    1271,26     425,58     845,68      19,11       0.00

                           BEST DESIGN IS NUMBER   1

                   SEARCH EFFORT WAS   5.3258% OF TOTAL ENUMERATION

                            * SLUDGE MIXING POINT
```

Figure B4. (continued)

design problem (i.e., design 1 in the "Sensitivity Phase" results of Figure B4). The same input data deck is used with the addition of the single design cards to the end of the deck. These cards give the number of the process unit selected at each stage of the particular system configuration under study. In this example they would be:

1, 2, 4, 7, 9, 30, 30, 30

14, 17, 21, 25

The output produced by EXEC/OP is shown in Figure B5. Each stage of the system (except those employing the null process) has its influent, effluent and sidestream waste streams described along with values of the input and computed design parameters for the process used at the stage. The abbreviations used for the components in the waste streams are explained in Table B3. The meaning of the input and output design parameter values can be found by looking up the process description in the listing of Appendix C.

The programmed version of EXEC/OP, listed in Appendix D, is dimensioned to accommodate up to 19 processing stages and 50 different types of process options. For those unit processes that require supplementary input data tables (vacuum filtration and centrifugation) a maximum of 5 different design levels may be used. The program is capable of generating up to 40 next-best designs.

```
                          EXECUTIVE PROGRAM
                        (OPTIMIZATION VERSION)
                                 FOR
            PRELIMINARY SYNTHESIS OF WASTE TREATMENT SYSTEMS

                 U.S. ENVIRONMENTAL PROTECTION AGENCY
              MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
                 SYSTEMS AND ECONOMIC ANALYSIS SECTION
                        CINCINNATI, OHIO 45268

                             CASE STUDY 1

                         PROCESS ALTERNATIVES
                         --------------------

OPTION  PROCESS  STAGE  SIDESTREAM
  NO.     NO.     NO.   DESTINATION                       REMARKS
------  -------  -----  -----------  ------------------------------------------------------------
   1      15       1         8       RAW WASTEWATER PUMPING
   2       1       2         8       PRELIMINARY TREATMENT
   3       2       3         8       PRIMARY SEDIMENTATION (40% SOLIDS REMOVAL)
   4       2       3         8                             (60% SOLIDS REMOVAL)
   5       3       4         6       ACTIVATED SLUDGE (MLVSS=2000, R=.3)
   6       3       4         6                        (MLVSS=2000, R=.5)
   7       3       4         6                        (MLVSS=3000, R=.3)
   8       3       4         6                        (MLVSS=3000, R=.5)
   9      12       5         6       CHLORINATION (0 MG/L DOSAGE)
  30       0       6         3       NULL PROCESS
  10      13       6         3       AIR FLOTATION THICKENING (TO 4% SOLIDS)
  30       0       7         3       NULL PROCESS
  11      18       7         3       AEROBIC DIGESTION (10 DAYS)
  30       0       8         3       NULL PROCESS
  12       8       8         3       GRAVITY THICKENING (TO 8% FOR PRI, 5% FOR MIXED SLUDGE)
  30       0       9         3       NULL PROCESS
  13      23       9         3       LIME STABILIZATION (200 LBS/TON)
  14       6       9         3       ANAEROBIC DIGESTION (15 DAYS)
  15       6       9         3                           (20 DAYS)
  16      18       9         3       AEROBIC DIGESTION (20 DAYS)
  17       8      10         3       GRAVITY THICKENING (TO 5% SOLIDS)
  18       9      10         3       ELUTRIATION (WASHWATER RATIO = 3, THICKENS TO 4%)
  30       0      10         3       NULL PROCESS
  19       7      11         3       VACUUM FILTRATION (10 GPH/SQ FT)
  20      17      11         3       CENTRIFUGATION
  21      10      11         3       SAND DRYING BEDS (30% CAKE SOLIDS)
  30       0      11         3       NULL PROCESS
  22      22      12         3       LAND SPREADING (10 MILE HAUL, 3000 $/AC, 400 LB N/AC/YR)
  23      22      12         3                      (30 MILE HAUL, 2000 $/AC, 600 LB N/AC/YR)
  24      22      12         3       LANDFILLING (10 MILE HAUL, 3000 $/AC)
  25      14      12         3       INCINERATION (2 LB/HR/SQ FT)
```

Figure B5. EXEC/OP output for single design evaluation

```
                        SELECTION CRITERIA
                        ------------------

     CRITERION                                WEIGHT          LIMIT
     ---------                                ------          -----

 1.  INITIAL CONSTR. COST, M$                   0.00       10000.00
 2.  ANNUAL O & M COST, $/MG                    0.00       10000.00
 3.  TOTAL ANNUAL COST, $/MG                    1.00       10000.00
 4.  ENERGY CONSUMED, KWH/MG                    0.00       10000.00
 5.  ENERGY PRODUCED, KWH/MG                    0.00           0.00
 6.  NET ENERGY CONSUMED, KWH/MG                0.00       10000.00
 7.  LAND REQUIRED, ACRES                       0.00       10000.00
 8.  UNDESIREABILITY INDEX                      0.00       10000.00


                          ECONOMIC DATA
                          -------------

       CONSTRUCTION COST INDEX                     2.8800
       WHOLESALE PRICE INDEX                       2.0000
       DIRECT HOURLY WAGE, $/HR                    5.9100
       FRACTION CHARGED TO SUPERVISION             0.1500
       COST ESCALATOR FOR MISC. FEES               1.3300
       COST OF ELECTRICITY, $/KWH                  0.0330
       FUEL CONVERSION EFFICIENCY                  0.3100
       DISCOUNT RATE                               0.0637
       CAPITAL RECOVERY FACTOR                     0.0899
```

Figure B5 (continued)

```
STAGE  PROCESS  SLUDGE,                                          SELECTION CRITERIA
 NO.   OPTION   TONS/DAY        1          2          3          4          5          6          7          8
-----  -------  --------    --------   --------   --------   --------   --------   --------   --------   --------
  1        1        0.00        0,91      10,09      32,39     141,37       0.00     141,37       0.00       0,00
  2        2        0,00        0,28       9,36      16,15       5,22       0.00       5,22       0.00       0,00
  3        4        6,71        0,59      12,37      26,89       8,71       0.00       8,71       0.00       0,00
  4        7        1,70        1,49      47,22      84,02     630,17       0.00     630,17       0.00       0,00
  5        9        0.00        0,29      17,52      24,65     120,53       0.00     120,53       0.00       0,00
  9*      14        8,41        0,64       6,52      22,35     299,38     418,92    -119,54       0.00       0,00
 10       17        4,39        0,11       1,57       4,27       1,21       0.00       1,21       0.00       0,00
 11       21        3,95        0,42      20,32      30,70       0,86       0.00       0,86       1,35       0,00
 12       25        3,95        0,88      12,99      34,73      99,67       0.00      99,67       0.00       0,00
                --------    --------   --------   --------   --------   --------   --------   --------   --------
SYSTEM VALUES       8,41        5,61     137,98     276,15    1307,13     418,92     888,21       1,35       0,00


                                    PROCESS PERFORMANCE CHARACTERISTICS
                                    -----------------------------------

                                            VOLUME FLOW, MGD
                                            CONCENTRATION, MG/L
                     CONSULT PROGRAM REFERENCE MANUAL FOR MEANING OF PROCESS INPUT AND OUTPUT DESIGN DATA.


                                          STAGE  1   PROCESS OPTION  1
                                          --------------------------

                                              INPUT DESIGN DATA:
   30.000      0.000      0.000      0.000      0.000      0.000      0.000      0.000
    0.000      0.000      0.000      0.000      0.000      0.000      0.000      1.000

                                              OUTPUT DESIGN DATA:
   14.805      0.000      0.000      0.000      0.000      0.000      0.000      0.000      0.000
    0.000      0.000      0.000      0.000      0.000      0.000      0.000      0.000      0.000
    0.000      0.000
```

Figure B5 (continued)

```
                          INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:
    Q          SOC         SNBC        SON         SOP         SFM         SBOD         VSS         TSS
 10.000      105.000      30.000      10.000       2.000      30.000     140.000     229.000     254.000
 10.000      105.000      30.000      10.000       2.000      30.000     140.000     229.000     254.000
  0.000        0.000       0.000       0.000       0.000       0.000       0.000       0.000       0.000
   DOC        DNBC          DN          DP          DFM         ALK        DBOD         NH3         NO3
 43.000       11.000      19.000       4.000     500.000     250.000      60.000      15.000       0.000
 43.000       11.000      19.000       4.000     500.000     250.000      60.000      15.000       0.000
  0.000        0.000       0.000       0.000       0.000       0.000       0.000       0.000       0.000

                                  STAGE  2   PROCESS OPTION  2
                                  --------------------------

                                       INPUT DESIGN DATA:
  1.000        0.000       0.000       0.000       0.000       0.000       0.000       0.000
  0.000        0.000       0.000       0.000       0.000       0.000       0.000       1.000

                                       OUTPUT DESIGN DATA:
  0.000        0.000       0.000       0.000       0.000       0.000       0.000       0.000       0.000
  0.000        0.000       0.000       0.000       0.000       0.000       0.000       0.000       0.000
  0.000        0.000

                          INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:
    Q          SOC         SNBC        SON         SOP         SFM         SBOD         VSS         TSS
 10.000      105.000      30.000      10.000       2.000      30.000     140.000     229.000     254.000
 10.056      108.813      33.970      10.453       2.077      33.632     139.709     238.192     266.851
  0.000        0.000       0.000       0.000       0.000       0.000       0.000       0.000       0.000
   DOC        DNBC          DN          DP          DFM         ALK        DBOD         NH3         NO3
 43.000       11.000      19.000       4.000     500.000     250.000      60.000      15.000       0.000
 43.462       11.000      22.449       4.924     500.000     262.320      60.864      15.018       0.000
  0.000        0.000       0.000       0.000       0.000       0.000       0.000       0.000       0.000
```

Figure B5 (continued)

```
                                    STAGE  3   PROCESS OPTION  4
                                    --------------------------

                                         INPUT DESIGN DATA:
   6,600      200,000      14,000       0,000       0,000       0,000       0,000       0,000
   0,000        0,000       0,000       0,000       0,000       0,000       1,000       1,000

                                        OUTPUT DESIGN DATA:
 868,395       11,580     251,400       0,000       0,000       0,000       0,000       0,000       0,000
   0,000        0,000       0,000       0,000       0,000       0,000       0,000       0,000       0,000
   0,000        0,000

                            INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:
     Q          SOC        SNBC         SON         SOP         SFM        SBOD         VSS         TSS
  10,056      108,813      33,970      10,453       2,077      33,632     139,709     238,192     266,851
  10,026       43,656      13,629       4,194       0,833      13,493      56,052      95,563     107,062
   0,030    21762,654    6793,905    2090,564     415,464    6726,337   27941,836   47638,387   53370,289
   DOC         DNBC          DN          DP         DFM         ALK        DBOD         NH3         NO3
  43,462       11,000      22,449       4,924     500,000     262,320      60,864      15,018       0,000
  43,462       11,000      22,449       4,924     500,000     262,320      60,864      15,018       0,000
  43,462       11,000      22,449       4,924     500,000     262,320      60,864      15,018       0,000

                                    STAGE  4   PROCESS OPTION  7
                                    --------------------------

                                         INPUT DESIGN DATA:
  30,000       30,000    3000,000       0,300     200,000       0,500      10,000       0,480
   7,000        0,050     800,000      30,000       1,000       1,000       1,000       1,000

                                        OUTPUT DESIGN DATA:
 116,915        4,140       0,008      12,500      10,000       0,266       0,792       0,792    1176,348
   0,000     1823,652     259,276     707,547      94,311       0,300       7,000 9848124,000    6838,975
   0,982        3,008

                            INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:
     Q          SOC        SNBC         SON         SOP         SFM        SBOD         VSS         TSS
  10,026       43,656      13,629       4,194       0,833      13,493      56,052      95,563     107,062
  10,000       10,505       7,409       2,028       0,238       5,725       7,386      24,275      30,000
   0,026     5543,186    3909,778    1069,922     125,568    3021,059    3897,638   12809,297   15830,355
   DOC         DNBC          DN          DP         DFM         ALK        DBOD         NH3         NO3
  43.462       11,000      22,449       4,924     500,000     262.320      60,864      15,018       0,000
  17,276       11,000      21,864       5,197     500,000     262.320      22,604      21,864       0,000
  17,276       11,000      21,864       5,197     500,000     262,320      22,604      21,864       0,000
```

Figure B5 (continued)

```
                                  STAGE  5   PROCESS OPTION  9
                                  ---------------------------

                                      INPUT DESIGN DATA:
    8.000      30.000     220.000      2.500    180.000      0.000      0.000      0.000
    0.000       0.000       0.000      0.000      0.000      1.000      1.000      1.000

                                      OUTPUT DESIGN DATA:
27852.027     121.618      38.006      0.000      0.000      0.000      0.000      0.000      0.000
    0.000       0.000       0.000      0.000      0.000      0.000      0.000      0.000      0.000
    0.000       0.000

                        INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:
      Q          SOC        SNBC        SON        SOP        SFM        SBOD        VSS        TSS
   10.000      10.505       7.409      2.028      0.238      5.725      7.386     24.275     30.000
   10.000      10.505       7.409      2.028      0.238      5.725      7.386     24.275     30.000
    0.000       0.000       0.000      0.000      0.000      0.000      0.000      0.000      0.000
     DOC        DNBC         DN          DP        DFM        ALK        DBOD        NH3        NO3
   17.276      11.000      21.864      5.197    500.000    262.320     22.604     21.864      0.000
   17.276      11.000      21.864      5.197    500.000    262.320     22.604     21.864      0.000
    0.000       0.000       0.000      0.000      0.000      0.000      0.000      0.000      0.000



                                  STAGE  9   PROCESS OPTION 14
                                  ---------------------------

                                      INPUT DESIGN DATA:
   15.000      30.000       0.500      0.310      0.000      0.000      0.000      0.000
    0.000       0.000       0.000      0.000      0.000      0.000      0.000      1.000

                                      OUTPUT DESIGN DATA:
    0.234    1154.105     112.291  76868.531  40369.461      0.000      0.000      0.000      0.000
    0.000       0.000       0.000      0.000      0.000      0.000      0.000      0.000      0.000
    0.000       0.000

                        INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:
      Q          SOC        SNBC        SON        SOP        SFM        SBOD        VSS        TSS
    0.056   14281.460    5463.608   1619.795    281.750   5017.286  16851.502  31573.547  36055.078
    0.056    5808.716    5463.608    671.640    116.826   5017.286    645.353  13824.745  18842.031
    0.000       0.000       0.000      0.000      0.000      0.000      0.000      0.000      0.000
     DOC        DNBC         DN          DP        DFM        ALK        DBOD        NH3        NO3
   31.384      11.000      22.180      5.050    500.000    262.320     43.216     18.176      0.000
  126.036      11.000     638.480    169.974    500.000   2462.513    215.118     18.176      0.000
    0.000       0.000       0.000      0.000      0.000      0.000      0.000      0.000      0.000
```

Figure B5 (continued)

```
                                              STAGE 10   PROCESS OPTION 17
                                              -------------------------

                                                  INPUT DESIGN DATA:
    0.900  50000.000    700.000      8.000   80000.000  20000.000  50000.000     16.000
    6.000      8.000      0.000      0.000       0.000      0.000      0.000      1.000

                                                  OUTPUT DESIGN DATA:
 1098.600      0.000      0.000      0.000
    0.000      0.000      0.000      0.000       0.000      0.000      0.000      0.000      0.000
    0.000      0.000                             0.000      0.000      0.000      0.000      0.000

                                  INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:
        Q        SOC       SNBC        SON         SOP        SFM       SBOD        VSS        TSS
    0.056   5808.716   5463.608    671.640     116.826   5017.286    645.353  13824.745  18842.031
    0.019  15414.252  14498.458   1782.293     310.015  13314.078   1712.535  36685.922  50000.000
    0.037    878.985    826.763    101.634      17.678    759.224     97.656   2091.984   2851.209
      DOC       DNBC         DN         DP         DFM        ALK       DBOD        NH3        NO3
  126.036     11.000    638.480    169.974     500.000   2462.513    215.118     18.176      0.000
  126.036     11.000    638.480    169.974     500.000   2462.513    215.118     18.176      0.000
  126.036     11.000    638.480    169.974     500.000   2462.513    215.118     18.176      0.000

                                              STAGE 11   PROCESS OPTION 21
                                              -------------------------

                                                  INPUT DESIGN DATA:
    0.300   2000.000      0.300      0.300       0.300     15.000      1.000   3000.000
    0.000      0.000      0.000      0.000       0.000      0.000      0.000      1.000

                                                  OUTPUT DESIGN DATA:
61423.039      0.000      0.000      0.000
    0.000      0.000      0.000      0.000       0.000      0.000      0.000      0.000      0.000
    0.000      0.000                             0.000      0.000      0.000      0.000      0.000

                                  INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:
        Q        SOC       SNBC        SON         SOP        SFM       SBOD        VSS        TSS
    0.019  15414.252  14498.458   1782.293     310.015  13314.078   1712.535  36685.922  50000.000
    0.003  88786.094  83511.117  10266.005    1785.687  76689.086   9864.201 211310.906 300000.000
    0.019    616.570    579.938     71.292      12.401    532.563     68.501   1467.437   2000.000
      DOC       DNBC         DN         DP         DFM        ALK       DBOD        NH3        NO3
  126.036     11.000    638.480    169.974     500.000   2462.513    215.118     18.176      0.000
  126.036     11.000    638.480    169.974     500.000   2462.513    215.118     18.176      0.000
  126.036     11.000    638.480    169.974     500.000   2462.513    215.118     18.176      0.000
```

Figure B5 (continued)

```
                                        STAGE 12   PROCESS OPTION 25
                                        ---------------------------

                                             INPUT DESIGN DATA:
    2.000      2.000     35.000      5.000      0.000  10000.000      1.000      0.300
    1.000      0.000      0.000      0.000      0.000      0.000      0.000      1.000

                                             OUTPUT DESIGN DATA:
  411.000 198371.703   7909.922   3075.518   7955.021      0.000      0.000      0.000      0.000
    0.000      0.000      0.000      0.000      0.000      0.000      0.000      0.000      0.000
    0.000      0.000

                             INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:
      Q          SOC       SNBC        SON        SOP        SFM       SBOD        VSS        TSS
    0.003  88786.094  83511.117  10266.005   1785.687  76689.086   9864.201 211310.906 300000.000
    0.000      0.000      0.000      0.000      0.000      0.000      0.000      0.000      0.000
    0.000      0.000      0.000      0.000      0.000      0.000      0.000      0.000      0.000
     DOC       DNBC         DN         DP        DFM        ALK       DBOD        NH3        NO3
  126.036     11.000    638.480    169.974    500.000   2462.513    215.118     18.176      0.000
    0.000      0.000      0.000      0.000      0.000      0.000      0.000      0.000      0.000
    0.000      0.000      0.000      0.000      0.000      0.000      0.000      0.000      0.000
```

Figure B5 (continued)

APPENDIX C

LISTING OF UNIT PROCESS DESCRIPTIONS

The following pages provide a listing of the design parameters used in the individual unit process model subroutines of EXEC/OP. The processes are listed in order of their subroutine identification number. Input parameters are those which must be supplied as input data to the program. Normally there are 16 parameters for each process. Of these 16, those that are not described in these pages are assigned the value of 0. Output parameters are those which are calculated during the execution of EXEC/OP.

The nominal sizes of all equipment are based on providing enough capacity for normal system operation. Actual sizes are computed by multiplying the nominal values by an excess capacity factor. These factors account for any reserve capacity needed to handle peak flows or for periodic cleaning and maintenance. They are specified as part of the input parameter list for each unit process.

Process: Preliminary Treatment

Subroutine ID Number: 1

Input Design Parameters:

1 - program control number: 0 = grit removal and flow measurement;
1 = grit removal, flow measurement, and screening

16 - excess capacity factor

Output Design Parameters: None

Notes:

1. Cost functions are from Ref. C1.

2. Energy consumption is from Refs. C2 and C3.

Process: Primary Sedimentation

Subroutine ID Number: 2

Input Design Parameters:

1 - fractional removal of influent suspended solids (.4-.6)

2 - ratio of solids concentration in settler underflow to solids concentration in settler influent (150 - 250)
3 - hours per week that sludge pumps are operated
15 - excess capacity factor for sludge pumps
16 - excess capacity factor for settler basin

Output Design Parameters:

1 - overflow rate for settler, gpd/sq. ft.
2 - surface area of settler, sq. ft./1000
3 - pumping capacity of sludge pumps, gpm

Notes:

1. Relation between fractional solids removal and overflow rate is from Ref. C4.

2. Cost functions are from Ref. C1.

3. Energy consumption is from Refs. C2 and C3.

Process: Activated Sludge (Aeration Basin and Final Settler)
Subroutine ID Number: 3

Input Design Parameters:

1 - effluent BOD, mg/l
2 - effluent suspended solids, mg/l
3 - mixed liquor volatile suspended solids, mg/l (2000 - 4000)
4 - sludge recycle ratio (.2-.8)
5 - half-velocity constant, mg/l (20-1000)
6 - true yield coefficient (.5-.7)
7 - maximum substrate removal rate coefficient, 1/day (3-20)
8 - biomass decay coefficient at a 1 day sludge age, 1/day (.1-.5)
9 - maximum removal rate coefficient for nitrification, 1/day (7)
10 - oxygen transfer efficiency of aeration equipment (.05-.08)
11 - overflow rate of final settler, gpd/sq. ft. (600-800)
12 - return sludge pumping head, ft. (10-20)
13 - excess capacity factor for final settler
14 - excess capacity factor for return sludge pumping
15 - excess capacity factor for air blowers
16 - excess capacity factor for aeration basin

Output Design Parameters:

1 - influent 5-day BOD, mg/l
2 - sludge age (solids retention time), days
3 - ratio of settler effluent to settler influent solids concentration
4 - surface area of final settler, sq. ft./1000
5 - maximum substrate removal rate coefficient, 1/day

6 - biomass decay coefficient, 1/day
7 - aeration basin volume, million gallons
9 - concentration of active biomass in aeration, mg/l
11 - concentration of refractory organic solids in aeration, mg/l
12 - concentration of nondegradable solids in aerator due to cell destruction, mg/l
13 - concentration of inert inorganic solids in aerator, mg/l
14 - concentration of BOD removed in aerator, mg/l
15 - sludge return ratio
16 - maximum removal rate coefficient for nitrification, 1/day
17 - diffused air requirement for the aerator, scf/day
18 - size of air blower required, cfm
19 - diffused air requirement per gallon of entering wastewater, scf/gal.
20 - volume of return sludge stream, mgd.

Notes:

1. BOD removal kinetics, sludge production, and air requirements are based on the models of Refs. C5, C6, and C7. The input kinetic parameters (items 5-9) are also based on these models.

2. Nitrification is normally assumed to begin after a sludge age of 5 days. If nitrification is not allowed then input design parameter 16 should equal 0.

3. Cost functions are from Ref. C1.

4. Energy consumption is from Refs. C3 and C8.

Process: Anaerobic Digestion

Subroutine ID Number: 6

Input Design Parameters:

1 - detention time, days (15-30)
2 - sludge temperature in digestor, degrees C (30-40)
3 - climate correction factor (1.0 for northern U.S., 0.5 for middle U.S., 0.3 for southern U.S.)
4 - efficiency in converting BTU content of digestor gas into equivalent kwh
16 - excess capacity factor

Output Design Parameters:

1 - rate constant for digestor, 1/day
2 - rate constant for biodegradable carbon, 1/day
3 - digestor volume, cu. ft./1000
4 - methane production, scf/day
5 - carbon dioxide production, scf/day

Notes:

1. Kinetics of biodegradable carbon destruction is described in Ref. C4.
2. Cost functions are from Ref. C1.
3. Energy consumption is from Refs. C2 and C3.

Process: Vacuum Filtration

Subroutine ID Number: 7

Input Design Parameters:

2 - hours per week of operation
3 - suspended solids concentration in filtrate, mg/l (1500-2500)
7 - cost of ferric chloride, $/lb
8 - cost of Lime, $/lb
10 - cost of polymer, $/lb
11 - identification number of supplementary input tables
16 - excess capacity factor

Supplementary Input Design Parameter Tables:

1 - filter dewatering rate, gph/sq. ft. (8-18)
2 - ferric chloride dosage, lb/ton (0-200)
3 - lime dosage, lb/ton (0-400)
4 - polymer dosage, lb/ton (0-40)

Output Design Parameters:

1 - percent moisture of filtered sludge
2 - filter surface area, sq. ft.
3 - filter cake dry solids production rate, lb/day

Notes:

1. Supplementary input data tables consist of parameter values for the 15 categories of sludge types shown below and are entered into the program input by column

	Raw	Limed	Digested	Digested + Elutriated	Heat Treated
Primary					
Secondary					
Primary + Secondary					

2. Prediction of cake moisture and required surface area is from Ref. C9.
3. Cost functions are from Ref. C1.
4. Energy consumption is from Refs. C2 and C3.

Process: Gravity Thickening

Subroutine ID Number: 8

Input Design Parameters:

1 - solids recovery ratio (.9-.98)
3 - overflow rate, gpd/sq. ft. (400-800)
5 - underflow thickened solids concentration for primary sludge, mg/l
6 - underflow thickened solids concentration for secondary sludge, mg/l
7 - underflow thickened solids concentration for mixed primary and secondary sludge, mg/l
8 - solids loading rate for primary sludge, lb/day/sq. ft. (20-30)
9 - solids loading rate for secondary sludge, lb/day/sq. ft. (4-18)
10 - solids loading rate for mixed primary and secondary sludge, lb/day/sq. ft. (8-20)
16 - excess capacity factor

Output Design Parameters:

1 - surface area of thickener, sq. ft.

Notes:

1. Cost functions are from Ref. C1.
2. Energy consumption is from Refs. C2 and C3.

Process: Elutriation

Subroutine ID Number: 9

Input Design Parameters:

1 - solids recovery ratio (.7-.9)
3 - ratio of wash water volume to influent volume (3)
4 - overflow rate, gpd/sq. ft. (400-600)
6 - underflow solids concentration for primary sludge, mg/l
7 - underflow solids concentration for secondary sludge, mg/l
8 - underflow solids concentration for mixed primary and secondary sludge, mg/l
9 - solids loading rate for primary sludge, lb/day/sq. ft. (20-30)
10 - solids loading rate for secondary sludge, lb/day/sq. ft. (4-18)
11 - solids loading rate for mixed primary and secondary sludge, lb/day/sq. ft. (8-20)
16 - excess capacity factor

Output Design Parameters:

1 - surface area of elutriation tank, sq. ft.

Notes:

1. Wastewater effluent is used as wash water stream
2. Cost functions are from Ref. C1.
3. Energy consumption is from Refs. C2 and C3.

Process: Sand Drying Beds

Subroutine ID Number: 10

Input Design Parameters:

2 - suspended solids concentration in filtrate, mg/l (200-3000)
3 - solid fraction of sludge cake for primary sludge (.2-.4)
4 - solid fraction of sludge cake for secondary sludge (.15-.3)
5 - solid fraction of sludge cake for mixed primary and secondary sludge
6 - detention time required for sludge holding tanks, days (5-20)
7 - excess capacity factor for sludge holding tanks
8 - cost of land for drying beds, $/acre
16 - excess capacity factor for drying beds

Output Design Parameters:

1 - bed area, sq. ft.

Notes:

1. Required bed area is computed as in Ref. C9.
2. Cost functions are from Ref. C1.
3. Energy consumption is from Ref. C3.

Process: Trickling Filter - Final Settler

Subroutine ID Number: 11

Input Design Parameters:

1 - effluent 5-day BOD, mg/l
2 - water temperature, degrees C
3 - hydraulic loading on filter (without recycle), mgd/acre (1040)
4 - specific surface area of the filter, sq. ft./cu. ft (935)
5 - effluent suspended solids, mg/l
6 - suspended solids concentration in sludge underflow from final settler (mg/l) (10000-40000)
7 - ratio of recycle flow to filter influent (14)
8 - overflow rate of final settler, gpd/sq. ft. (600-800)
9 - sludge production factor, lbs sludge/lb BOD removed (.4-.65)
10 - ratio of settled to unsettled effluent BOD (.5)
14 - excess capacity factor for recirculation pumps
15 - excess capacity factor for final settler
16 - excess capacity factor for filter

Output Design Parameters:

1 - surface area of final settler, sq. ft./1000
2 - volume of trickling filter, 1000 cu ft
3 - area of filter face, acres
4 - depth of filter, ft.

Notes:

1. Recycle of filter effluent and use of final settler are optional.
2. Filter is sized according to Ref. C10.
3. Cost functions are from Ref. C1.
4. Energy consumption is from Refs. C3 and C8.

Process: Chlorination - Dechlorination

Subroutine ID Number: 12

Input Design Parameters:

1 - dose of chlorine, mg/l (2-15)
2 - chlorine contact time, minutes (15-30)
3 - cost of chlorine, \$/ton
4 - dose of sulfur dioxide for dechlorination, mg/l (2.5)
5 - cost of sulfur dioxide, \$/ton
14 - excess capacity factor for the sulfur dioxide feed system
15 - excess capacity factor for the chlorine feed system
16 - excess capacity factor for the contact basin

Output Design Parameters:

1 - volume of the chlorine contact basin, cu. ft.
2 - amount of chlorine used, tons/yr.
3 - amount of sulfur dioxide used, tons/yr.

Notes:

1. Costs are from Ref. C1.
2. Energy consumption is from Ref. C3.

Process: Flotation Thickening

Subroutine ID Number: 13

Input Design Parameters:

1 - solids recovery ratio (.95)
2 - suspended solids concentration of thickened sludge, mg/l
3 - overflow rate, gpd/sq. ft. (700-1200)
4 - solids loading rate, lb./day/sq. ft. (24-96)
5 - hours per week of operation

6 - dose of polymer, lb./ton
7 - cost of polymer, $/ton
16 - excess capacity factor

Output Design Parameters:

1 - surface area of each thickener used, sq. ft.
2 - number of thickeners used
3 - total surface area required, sq. ft.

Notes:

1. Thickeners are chosen from among a set of commercially available sizes.
2. Costs are taken from Ref. C1.
3. Energy consumption is from Ref. C8.

Process: Multiple Hearth Incineration

Subroutine ID Number: 14

Input Design Parameters:

1 - mass loading, lb./hr./sq. ft. of hearth area (2)
2 - number of multiple hearth incinerators (2)
3 - hours per week of operation
4 - number of start-up periods per week
5 - wind velocity, mph
6 - higher heat value for volatiles, BTU/lb. (10000)
7 - type of fuel used; 1 = fuel oil, 2 = natural gas, 3 = digestor gas
8 - cost of fuel oil, $/gal.
9 - cost of natural gas, $/1000 cu. ft.
10 - efficiency in converting BTU content of exhaust gas into equivalent kwh
16 - excess capacity factor

Output Design Parameters:

1 - total hearth area, sq. ft.
2 - total fuel usage, lb./yr.
3 - amount of dry solids incinerated, lb./day.
4 - cost of electrical power to operate the incinerator, $/yr.
5 - cost of fuel to operate the incinerator, $/yr.

Notes:

1. Hearth sizing and fuel requirements are computed as in Refs. C9 and C11 on the basis of exit gas temperature of 800°F.

2. Costs are from Ref. C11. Does not include air pollution control equipment or ash disposal.

3. Energy consumption is from Ref. C11.

4. Heat value of exhaust gas is computed as in Ref. C12 assuming ambient temperature of 60°F.

Process: Raw Wastewater Pumping

Suroutine ID Number: 15

Input Design Parameters:

1 - pumping head, ft. (10-30)
16 - excess capacity factor

Output Design Parameters:

1 - peak flow capacity of the raw wastewater pumping system, mgd

Notes:

1. Costs are from Ref. C1.
2. Energy consumption is from Ref. C8.

Sludge Holding Tanks

Subroutine ID Number: 16

Input Design Parameters:

1 - dentention time, days
16 - excess capacity factor

Output Design Parameters:

1 - volume of holding tanks, cu. ft./1000

Notes:

1. Costs are from Ref. C1.

Process: Centrifugation

Subroutine ID Number: 17

Input Design Parameters:

3 - hours per week of operation
6 - cost of polymer, $/lb.
8 - minimum number of centrifuges to be used
9 - identification number of supplementary input tables

Supplementary Input Design Parameter Tables:

1 - solids recovery ratio (.5-.9)
2 - percent solids of centrifuged sludge (5-35)
3 - dose of conditioning polymer, lb/ton (0-15)
4 - sludge feed rate, gpm (10-200)

Output Design Parameters:

1 - design capacity of the centrifuges, gpm
2 - dry solids processed, tons/yr.
3 - capital recovery factor for centrifuges based on a 10 year lifetime
4 - size of each centrifuge used, gpm
5 - number of centrifuges used

Notes:

1. Supplementary input data tables consist of parameter values for the 15 categories of sludge types shown below and are entered into the program input by column.

	Raw	Limed	Digested	Digested + Elutriated	Heat Treated
Primary					
Secondary					
Primary + Secondary					

2. Determination of the number and sizes of centrifuges is described in Ref. C9.

3. Costs are from Ref. C1.

4. Energy consumption is based on 1 hp/gpm as quoted in Ref. C13.

Process: Aerobic Digestion

Subroutine ID Number: 18

Input Design Parameters:

4 - sludge temperature, degrees C
5 - process detention time, days (12-22)
6 - biomass decay rate coefficient at a sludge age of 1 day at 20°C, 1/days (.1-.5)
7 - true yield coefficient for 5-day BOD (.5-.7)
10 - maximum removal rate coefficient for nitrification, 1/day (7)
11 - oxygen transfer efficiency (.05-.08)
15 - excess capacity factor for blowers
16 - excess capacity factor for digester

Output Design Parameters:

1 - digester volume, cu. ft./1000
2 - size of air blower, cfm

Notes:

1. Complete mix, continuous flow operation is assumed.

2. Solids destruction is modeled as in Ref. C14. Adjustment of biomass decay rate to reflect solids retention time in both digester and activated sludge unit is from Ref. C6.

3. Costs are from Ref. C1.

4. Energy consumption is from Ref. C8.

Process: Truck Transport/Land Disposal of Sludge

Subroutine ID Number: 22

Input Design Parameters:

1 - working hours per year
2 - one-way hauling distance, miles
3 - amortization period for trucks, years
4 - fuel cost, $/gal.
5 - cost of land, $/acre
6 - program control; 0 = land spreading, 1 = landfilling
7 - storage period for liquid sludge, years (.1-.5)
8 - maximum allowable nitrogen application rate, lb./acre/yr. (600)
9 - land spreading site preparation cost, $/acre
10 - land spreading application cost, $/ton
15 - excess capacity factor for trucks
16 - excess capacity factor for sludge storage

Output Design Parameters:

1 - number of trips per year per truck
2 - number of trips per year by all trucks
3 - total number of trucks
4 - volume of sludge storage, cu. ft./1000
5 - amount of dry solids applied to land, tons/yr.
6 - land area required, acres
7 - equivalent annual interest cost on capital investment in land, $/yr.
8 - capital cost of land, $
9 - capital recovery factor for trucks

Notes:

1. Sludge spreading may involve either liquid or dewatered sludge. Only dewatered sludge may be landfilled. Dewatered sludge has a solids content of 15% or more.
2. Land used for sludge spreading has a resale value equal to its initial cost.
3. Costs and energy consumption of truck transport are from Ref. C15.
4. Costs for landfills are from Ref. C16.
5. Costs of storage lagoons are from Ref. C1.
6. Energy consumption for land spreading and landfilling is from Ref. C3.

Process: Lime Stabilization

Subroutine ID Number: 23

Input Design Parameters:

1 - lime dosage, lb./ton of dry solids (200-500)
2 - cost of lime, $/ton
16 - excess capacity factor

Output Design Parameters:

1 - lime addition rate, lb./day
2 - amount of sludge treated, tons of dry solids/day

Notes:

1. Costs are from Ref. C1.
2. Energy consumption is from Ref. C3.

Process: Rotating Biological Contactor - Final Settler

Subroutine ID Number: 24

Input Design Parameters:

1 - effluent 5-day BOD, mg/l
2 - number of stages in series for the process (4)
3 - temperature of the wastewater, degrees C
4 - rate constant for BOD removal at 20°C, gpd/sq. ft. (6-9)
5 - rate constant for nitrification at 20°C, gpd/sq. ft. (4-5)
6 - overflow rate for final settler, gpd/sq. ft. (600-800)
7 - concentration of BOD at which nitrification begins, mg/l (20-30)
10 - sludge production factor, lb sludge/lb BOD removed

8 - concentration of waste solids from the final settler underflow, percent
9 - cost of installed concrete, $/cu. yd.
15 - excess capacity factor for the final settler
16 - excess capacity factor for the rotating biological contactor

Output Design Parameters:

1 - loading rate for BOD removal adjusted for water temperature, gpd/sq. ft.
2 - loading rate for nitrification adjusted for water temperature, gpd/sq. ft.
3 - area per contactor stage, sq. ft.
4 - total active contactor area, sq. ft.
5 - number of stages required to achieve the BOD concentration at which nitrification begins
6 - number of remaining stages for nitrification
7 - fraction of influent BOD remaining in effluent
8 - percentage ammonia nitrogen removal
9 - overall hydraulic loading, gpd/sq. ft.
10 - surface area of final settler, sq. ft.
11 - solids wasting rate, lb. dry solids/day
12 - fraction of suspended solids remaining after settling
13 - number of 100,000 sq. ft. shafts per stage
14 - number of 100,000 sq. ft. shafts required
15 - materials and supplies cost, $/yr.
16 - electrical power cost, $/yr.
17 - labor cost, $/yr.

Notes:

1. Waste stream transformation and sludge production is modeled as in Ref. C8.
2. Cost functions are from Ref. C1.
3. Energy consumption is from Ref. C3 and C8.

Process: Primary Sedimentation - Activated Sludge - Waste Activated Sludge Returned to Primary Clarifier

Subroutine ID Number: 25

Input Design Parameters:

1 - option number assigned to primary clarifier unit

2 - option number assigned to activated sludge unit

Supplementary Input Design Parameters:

1 through 16 - see Primary Sedimentation subroutine

17 through 32 - see Activated Sludge subroutine

Output Design Parameters:

1 through 20 - see Activated Sludge subroutine

Notes:

1. See notes for Primary Sedimentation and Activated Sludge subroutines.

Process: Nonoxidative Heat Treatment

Subroutine ID Number: 26

Input Design Parameters:

4 - operating temperature, degrees C (150-220)
5 - hours per week of operation
6 - number of start-ups per week
7 - fuel cost, $/million BTU
8 - detention time for sludge holding tanks, days
9 - excess capacity factor for sludge holding tanks
16 - excess capacity factor for heat treatment

Output Design Parameters:

1 - capacity of heat treatment unit, gpm
2 - fraction of suspended COD remaining in effluent
3 - fraction of volatile suspended solids remaining in effluent
4 - annual heat requirement, million BTU/yr.

Notes:

1. Reduction in BOD and volatile solids is based on operating temperature as described in Ref. C17.

2. Costs are from Ref. C18.

3. Energy consumption is from Ref. C19.

REFERENCES

C1. Patterson, W. L. and Banker, R. F., "Estimating Costs and Manpower Requirements for Conventional Wastewater Treatment Facilities", Water Pollution Control Research Series 17090 DAN 10/71, U.S. Environmental Protection Agency (1971).

C2. Smith, R., "Electrical Power Consumption for Municipal Wastewater Treatment", EPA-R2-73-281, U.S. Environmental Protection Agency, Cincinnati, Ohio (1973).

C3. Wesner, G. M., et al., "Energy Conservation in Municipal Wastewater Treatment", EPA-430/9-77-001, U.S. Environmental Protection Agency, Office of Water Program Operations, Washington, D.C. (1977).

C4. Smith, R., "Preliminary Design of Wastewater Treatment Systems", Jour. San. Eng. Div., Proc. Amer. Soc. Civil Engr., 95, 117, (1969).

C5. Lawrence, A. W. and McCarty, P. L., "Unified Basis for Biological Treatment Design and Operation", Jour. San. Eng. Div., Proc. Civil Engr., 96, 757, (1970).

C6. Goodman, B. L. and Englande, A. J., "A Unified Model of the Activated Sludge Process", Jour. Water Poll. Control Fed. 46, 312 (1974).

C7. Christensen, D. R. and McCarty, P. L., "BIOTREAT: A Multi-Process Biological Treatment Model" presented at the Annual Conference of the Water Pollution Control Federation, Denver, Colorado, October 8, (1974).

C8. Eilers, R. G., et al., "Applications of Computer Programs in the Preliminary Design of Wastewater Treatment Facilities - Section II", EPA-600/2-78-1856, U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory, Cincinnati, Ohio (1978).

C9. Smith, R. and Eilers, R. G., "Computer Evaluation of Sludge Handling and Disposal Costs", Proceedings of the 1975 National Conference on Municipal Sludge Management and Disposal, Anaheim, California, August 18-20 (1975).

C10. Roesler, J. F. and Smith R., "A Mathematical Model for a Trickling Filter", U.S. Department of Interior, Federal Water Pollution Control Administration, Advanced Waste Treatment Research Laboratory, Cincinnati, Ohio (1969).

C11. Unterberg, R., Sherwood, J., and Schneider, G. R., "Computerized Design and Cost Estimation for Multiple Hearth Sludge Incinerators", available from National Technical Information Service as NTIS-PB-211-264, July (1971).

C12. Smith, R., "Total Energy Consumption for Municipal Wastewater Treatment", EPA-600/2-78-149, U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory, Cincinnati, Ohio (1978).

C13. Haug, R. T., Tortorici, L. D., and Raksit, S. K., "Sludge Processing and Disposal: A State of the Art Review", Regional Wastewater Solids Management Program, Los Angeles County/Orange County Metropolitan Area, April (1977).

C14. Adams, C. E., Jr., et al., "Modification to Aerobic Digestion Design", Water Res., 8, 213 (1974).

C15. Ettlich, W. F., "Transport of Sewage Sludge", EPA-600/2-77-216, U.S. Environmental Protection Agency, Cincinnati, Ohio (1977).

C16. Wyatt, J. M. et al, "Sludge Processing, Transportation and Disposal/Research Recovery: A Planning Perspective", EPA-440/9-76-002, U.S. Environmental Protection Agency, Washington, D.C. (1975).

C17. Heidman, J. A., "Oxidative and Nonoxidative Heat Treatment of Wastewater Sludges - Part I:, Internal Memorandum, U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory, Cincinnati, Ohio, May 3 (1978).

C18. Ewing, L. J., Jr., et al., "Effects of Thermal Treatment of Sludge on Municipal Wastewater Costs", Final Report for EPA Contract No. 68-03-2186, U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory, Cincinnati, Ohio (1978).

C19. Heidman, J. A., "Oxidative and Nonoxidative Heat Treatment of Wastewater Sludges - Part II", Internal Memorandum, U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory, Cincinnati, Ohio, June 29 (1978).

APPENDIX D - PROGRAM LISTING

```
C                        EXECOP - MAIN
C
C        EXEC/OP - OPTIMIZATION VERSION OF EPA EXECUTIVE PROGRAM
C
C        SELECTS BEST COMBINATION OF UNIT PROCESSES FOR TREATING
C        WASTEWATER AND DISPOSING OF RESIDUAL SLUDGES.
C        SELECTION CRITERIA INCLUDES COST, ENERGY, LAND UTILIZATION,
C        AND A SUBJECTIVE PROCESS UNDESIREABILITY RATING.
C        PROGRAM CAN ALSO IDENTIFY UP TO 40 NEXT-BEST DESIGNS.
C
C                WRITTEN BY L. ROSSMAN, EPA, MERL, DECEMBER 1978
C
C
         INTEGER OS1,OS2
         COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     1          INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     2          ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     3          CF,EER,EEP,ALAND
         COMMON/PROC/ NPROC(20),KPROC(10,20),NWPS,NPSPS,NSSPS,
     2                NTPS,NTPU,JSTRM(22),JSIDE(20),P(20,10),
     3                IPOPT(20),PINFLO(20),EFFSTD(20),ISC(45),IDC(45)
         COMMON/COST/ C(20,10),CP(10),RHS(10),W(10),UDR(50),
     2                IPSAVE(40,20),JMSAVE(40),TEPMAX,KMAX,FACTR,TUPE
     3                ,EEPMAX(20)
         COMMON/TABLES/ DUMMY(600)
         DIMENSION CSIM(10),CSAVE(10)
         DIMENSION PSAVE(20,10)
         EQUIVALENCE (PSAVE(1,1),IPSAVE(1,1)),(JMIX,JSTRM(21))
C
C
C                INITIALIZE COUNTERS AND UPPER BOUND
C
         MITMAX=10
         MITER=1
         TUPE=0.
         TSE=0.
         NITSUM=0
         ZUB=1.E20
         NPHASE=1
C
         INP=5
         IO=5
C
C                CALL SUBROUTINE THAT READS IN INPUT
C
         ISW=0
         CALL INPUT(ISW)
C
C                INITIALIZE PLANT INFLOW AND RECYCLE PENALTIES
C
25       DO 30 I=1,20
         SMATX(I,1)=PINFLO(I)
         DO 30 K=1,10
         PSAVE(I,K)=0.
30       P(I,K)=0.
         P(2,5)=-10000.
         P(2,6)=-10000.
         TEPMAX=W(5)*TEPMAX
```

```
C
C
C                 IF SYSTEM DESIGN IS FIXED, EVALUATE PERFORMANCE
         IF (ISW .EQ. 0) GO TO 40
         CALL SOLVE(TCS,CSIM,NITER)
         CALL OUTPUT(ISW,1,TCS,-1.,-1.)
         STOP
C
C
C                 OPTIMIZATION PHASE
C                 ------------------
C
C
40       WRITE(IO,400)
400      FORMAT(////,49X,'OPTIMIZATION PHASE'/49X,18('_'))
C
C
C                 PERFORM SYSTEM OPTIMIZATION USING PENALTY TERMS TO
C                 ACCOUNT FOR SLUDGE RECYCLE FLO*S.
45       IF(MITER.GT.MITMAX)GO TO 300
         TCO=1.01*ZUB
         CALL OPTIM(NPHASE,1,1.0,TCO.TCP,IFEAS)
         IF(IFEAS.GT.0)GO TO 90
         WRITE(IO,50)
50       FORMAT(/42X,' NO FEASIBLE DESIGN CAN BE FOUND'//)
         IF(MITER.EQ.1)STOP
         GO TO 300
C
C
C                 FIND EXACT PERFORMANCE OF CANDIDATE OPTIMAL SYSTEM DESIGN
90       CALL SOLVE(TCS,CSIM,NITER)
         TSE=TSE+1.
         NITSUM=NITSUM+NITER
         WRITE(IO,100) MITER,TCS-TEPMAX
100      FORMAT(////52X,'DESIGN ',I3/52X,10('_')//
     2          39X,' EXACT SYSTEM VALUE',6X,F12.3)
         WRITE(IO,105) TCO-TEPMAX,TCP
105      FORMAT(39X,' APPROX. SYSTEM VALUE',4X,F12.3/
     2          39X,' PENALTY FROM RECYCLES',3X,F12.3)
C
C
C                 IF TCS VALUE WAS REACHED ONCE BEFORE,STOP WITH CURRENT
C                 UPPER BOUND AS OPTIMAL.
110      CONTINUE
         IF(MITER.EQ.1)GO TO 250
         J2=MITER-1
         DO 240 JJ=1,J2
         IF(CSAVE(JJ).EQ.TCS)GO TO 295
240      CONTINUE
C
C
C                 PERFORM FEASIBILITY CHECK
250      IFEAS=1
         DO 230 K=1,10
         IF(CSIM(K).GT.RHS(K))IFEAS=0
230      CONTINUE
C
C
C                 SAVE OBJECTIVE VALUE AND PRINT DESIGN OF CURRENT SYSTEM
         CALL OUTPUT(ISW)
         IF(IFEAS.EQ.0)WRITE(IO,235)
235      FORMAT(//42X,'*** SOLUTION IS NOT FEASIBLE ***')
         CSAVE(MITER)=TCS
         IF(IFEAS.EQ.0)GO TO 260
C
C
C                 IF TCS LESS THAN CURRENT UPPER BOUND, REPLACE UPPER BOUND
         IF(ZUB.LE.TCS) GO TO 260
         ZUB=TCS
         DO 255 I=1,20
         DO 255 K=1,10
255      PSAVE(I,K)=P(I,K)
```

```
        MITMIN=MITER
260     MITER=MITER+1
        IF(MITER.GT.MITMAX)GO TO 300
C
C               COMPUTE NEW RECYCLE PENALTY  VALUES
C
        CALL PNALTY(CSIM)
C
C               RE-ARRANGE ENTRIES IN PROCESS LISTS SO THAT CANDIDATE
C               OPTIMAL PROCESS TRAIN APPEARS FIRST
C
        DO 290 J=1,NTPS
        L1=NPROC(J)
        DO 275 L=1,L1
        IF(KPROC(L,J).EQ.IPOPT(J))GO TO 285
275     CONTINUE
285     LSTAR=L
        IF(LSTAR.EQ.1)GO TO 290
        KSAVE=KPROC(LSTAR,J)
        L1=LSTAR-1
        DO 280 L=1,L1
        L2=LSTAR-L+1
        KPROC(L2,J)=KPROC(L2-1,J)
280     CONTINUE
        KPROC(1,J)=KSAVE
290     CONTINUE
C
C               BEGIN ANOTHER OPTIMIZATION ITERATION
        GO TO 45
C
295     WRITE(IO,305) JJ
305     FORMAT(/45X,'SAME SYSTEM AS DESIGN ',I3)
C
C               SENSITIVITY PHASE
C               -----------------
C
300     NPHASE=2
        IF(KMAX.LE.1) GO TO 360
        WRITE(IO,405)
405     FORMAT(////,49X,'SENSITIVITY PHASE'/49X,17('_'))
C
C               PERFORM SYSTEM OPTIMIZATION USING RECYCLE PENALTY VALUES
C               ASSOCIATED WITH OPTIMAL SYSTEM DESIGN (PSAVE) AND IDENTIFY
C               ALL DESIGNS WITHIN 'FACTOR' OF OPTIMUM.
C
        DO 310 I=1,20
        DO 310 K=1,10
310     P(I,K)=PSAVE(I,K)
        LIMIT=KMAX
        FACTOR=FACTR
        TCO=1.01*ZUB
        CALL OPTIM(NPHASE,LIMIT,FACTOR,TCO,TCP,IFEAS)
        IF(IFEAS.EQ.0)STOP
C
C               EVALUATE TRUE PERFORMANCE OF EACH DESIGN
C
        ZUB=100.E20
        DO 350 KS=1,LIMIT
        DO 330 J=1,NTPS
330     IPOPT(J)=IPSAVE(KS,J)
        JMIX=JMSAVE(KS)
        CALL SOLVE(TCS,CSIM,NITER)
        TSE=TSE+1.
        NITSUM=NITSUM+NITER
        WRITE(IO,100) KS,TCS-TEPMAX
        CALL OUTPUT(ISW)
        IF(ZUB.LE.TCS)GO TO 350
        ZUB=TCS
        MITMIN=KS
350     CONTINUE
360     WRITE(IO,370)MITMIN
370     FORMAT(//45X,'BEST DESIGN IS NUMBER ',I3)
C
C               COMPUTE SEARCH EFFICIENCY
C
        FEM=1.
        DO 380 J=1,NTPS
380     FEM=FEM*NPROC(J)
        FEM=FEM*NTPS*NITSUM/TSE
        SEFF=TUPE/FEM*100.
        WRITE(IO,390)SEFF
390     FORMAT(//33X,'SEARCH EFFORT WAS ',F8.4,'% OF TOTAL',
     2               ' ENUMERATION')
        WRITE(IO,395)
395     FORMAT(//47X,' * SLUDGE MIXING POINT')
        STOP
        END
C
C
C                       INPUT SUBROUTINE
C
        SUBROUTINE INPUT(ISW)
C
        INTEGER OS1,OS2
        COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     1         INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     2         ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     3         CF,EER,EEP,ALAND
        COMMON/PROC/ NPROC(20),KPROC(10,20),NWPS,NPSPS,NSSPS,
     2               NTPS,NTPU,JSTRM(22),JSIDE(20),P(20,10),
     3               IPOPT(20),PINFLO(20),EFFSTD(20),ISC(45),IDC(45)
        COMMON/COST/ C(20,10),CP(10),RHS(10),W(10),UDR(50),
     2               IPSAVE(40,20),JMSAVE(40),IEPMAX,KMAX,FACTR,TUPE
     3               ,EEPMAX(20)
        COMMON/TABLES/ VACF1(3,5,5),VACF5(3,5,5),VACF6(3,5,5),VACF9(3,5,5)
     2       ,CENT1(3,5,5),CENT2(3,5,5),CENT5(3,5,5),CENT7(3,5,5)
        DIMENSION TITLE(40)
        EQUIVALENCE (JMIX, JSTRM(21))
C
C               READ IN JOB TITLE
C
        READ(INP,10)TITLE
10      FORMAT(40A2)
        WRITE(IO,15)
15      FORMAT(/49X,'EXECUTIVE PROGRAM'/46X,'(OPTIMIZATION VERSION)'
     2         /56X,'FOR'/33X,'PRELIMINARY SYNTHESIS OF WASTE ',
     3         'TREATMENT SYSTEMS')
        WRITE(IO,20)
20      FORMAT(//39X,'U.S. ENVIRONMENTAL PROTECTION AGENCY'/36X,
     2  'MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY'/39X,
     3  'SYSTEMS AND ECONOMIC ANALYSIS SECTION'/46X,
     4  'CINCINNATI, OHIO 45268')
        WRITE(IO,25) TITLE
25      FORMAT(////17X,40A2)
C
C               READ IN INFLUENT WASTE CHARACTERISTICS, EFFLUENT
C               DISCHARGE STANDARDS, AND ECONOMIC DATA.
C
        PINFLO(1)=1.
        PINFLO(20)=0.
        READ(INP,1) (PINFLO(I),I=2,19)
        READ(INP,1) (EFFSTD(I),I=1,5)
        READ(INP,1) CCI,WPI,RI,YRS,DHR,PCT,CKWH,RATIO,CF
        AF=RI*(1.+RI)**YRS/((1.+RI)**YRS-1.)
```

```
C
C               READ IN # WASTEWATER PROCESS STAGES,
C                # SECONDARY SLUDGE PROCESS STAGES,
C               # PRIMARY SLUDGE PROCESS STAGES, TOTAL # PROCESS UNITS,
C               SLUDGE RECYCLE STAGE, AND STABILIZATION STAGES FOR
C               SECONDARY AND PRIMARY SLUDGES.
C
      READ(INP,2)NWPS,NSSPS,NPSPS,NTPU,JRECYC
C
C               ESTABLISH SEGMENT ID NOS. FOR PROCESS STAGES AND ZERO OUT
C               LENGTH OF PROCESS LISTS.
C
      NTPS=NWPS+NPSPS+NSSPS
C
C               JSTRM CODE
C
C       1-2   = WASTEWATER PROCESSING STAGES
C       3-4   = SECCNDARY SLUDGE PROCESSING STAGES
C       5-6   = PRIMARY SLUDGE PROCESSING STAGES
C       7-10  = SLUDGE STREAM FROM WASTEWATER TREATMENT
C      11-12  = SECONDARY SLUDGE RECYCLE STREAM
C      13-14  = PRIMARY SLLUDGE RECYCLE STREAM
C      15-17  = WASTEWATER, SECONDARY AND PRIMARY SLUDGE EFFLUENT STREAMS
C         20  = PECYCLE RETURN STAGE
C         21  = SECONDARY AND PRIMARY SLUDGE MIXING STAGE
C         22  = NULL PROCESS NUMBER
C
      JSTRM(1)=1
      JSTRM(2)=NWPS
      JSTRM(3)=JSTRM(2)+1
      JSTRM(4)=JSTRM(3)+NSSPS-1
      JSTRM(5)=JSTRM(4)+1
      JSTRM(6)=JSTRM(5)+NPSPS-1
      JSTRM(7)=JSTRM(6)+1
      JSTRM(10)=JSTRM(7)+NWPS-1
      JSTRM(11)=JSTRM(10)+1
      JSTRM(12)=JSTRM(11)+NSSPS-1
      JSTRM(13)=JSTRM(12)+1
      JSTRM(14)=JSTRM(13)+NPSPS-1
      JSTRM(15)=JSTRM(14)+1
      JSTRM(16)=JSTRM(15)+1
      JSTRM(17)=JSTRM(16)+1
      JSTRM(20)=JRECYC
      DO 30 J=1,NTPS
30    NPROC(J)=0
      N=0
C
C               READ IN STAGES ASSIGNED TO SLUDGE STREAMS FROM
C               WASTEWATER TREATMENT
C
      READ(INP,2) (JSIDE(I),I=1,NWPS)
      JJ=JSTRM(3)
      DO 32 I=JJ,NTPS
32    JSIDE(I)=JRECYC
C
C               READ IN INFORMATION ON ALTERNATIVE PROCESS UNITS
C
      DO 33 I=1,NTPS
33    EEPMAX(I)=0.
      WRITE(IO,35)
35    FORMAT(////47X,'PROCESS ALTERNATIVES'/47X,20('_'))
      WRITE(IO,40)
40    FORMAT(//' OPTION  PROCESS  STAGE  SIDESTREAM'/
     2  '   NO.      NO.      NO.   DESTINATION',37X,'REMARKS'
     3  ' ______  _______  _____  ___________',2X,80('_'))
```

```
          DO 60 K=1,NTPU
          READ(INP,3)J,N,IPROC,EMAX,UDR(N)
          IF (EMAX .GT. EEPMAX(J)) EEPMAX(J)=EMAX
          READ(INP,45)(TITLE(JJ),JJ=1,40)
 45       FORMAT(40A2)
          WRITE(IO,50) N,IPROC,J,JSIDE(J), (TITLE(JJ),JJ=1,40)
 50       FORMAT(1X,I4,3I8,9X,40A2)
          NPROC(J)=NPROC(J)+1
          KPROC(NPROC(J),J)=N
          IP(N)=IPROC
          IF(IPROC.EQ.0)JSTRM(22)=N
          IF(IPROC.EQ.0)GO TO 60
          READ(INP,1)(DMATX(I,N),I=1,16)
          IF(IPROC.EQ.7)GO TO 51
          IF(IPROC.EQ.17)GO TO 53
          IF(IPROC.EQ.25)GO TO 55
          GO TO 60
 51       L=DMATX(11,N)
          READ(INP,1)((VACF1(I,JJ,L),I=1,3),JJ=1,5)
          READ(INP,1)((VACF5(I,JJ,L),I=1,3),JJ=1,5)
          READ(INP,1)((VACF6(I,JJ,L),I=1,3),JJ=1,5)
          READ(INP,1)((VACF9(I,JJ,L),I=1,3),JJ=1,5)
          GO TO 60
 53       L=DMATX(9,N)
          READ(INP,1)((CENT1(I,JJ,L),I=1,3),JJ=1,5)
          READ(INP,1)((CENT2(I,JJ,L),I=1,3),JJ=1,5)
          READ(INP,1)((CENT5(I,JJ,L),I=1,3),JJ=1,5)
          READ(INP,1)((CENT7(I,JJ,L),I=1,3),JJ=1,5)
          GO TO 60
 55       NSAVE=DMATX(1,N)
          READ(INP,1) (DMATX(I,NSAVE),I=1,16)
          NSAVE=DMATX(2,N)
          READ(INP,1) (DMATX(I,NSAVE),I=1,16)
          GO TO 60
 60       CONTINUE
C
C                 READ IN SELECTION CRITERIA DATA
C
          DO 115 K=1,10
 115      W(K)=0.
          WRITE(IO,120)
 120      FORMAT(////48X,'SELECTION CRITERIA'/48X,18('_')//)
          WRITE(IO,125)
 125      FORMAT(32X,'CRITERION',25X,'WEIGHT',11X,'LIMIT',
     2    /32X,9('_'),25X,6('_'),11X,5('_')/)
          READ(INP,1)(W(K),K=1,8)
          READ(INP,1)(RHS(K),K=1,8)
          WRITE(IO,130)(W(K),RHS(K),K=1,4)
 130      FORMAT(25X,' 1.  INITIAL CONSTR. COST, M$  ',6X,2(F10.2,8X),
     2          /25X,' 2.  ANNUAL O & M COST, $/MG',9X,2(F10.2,8X),
     3          /25X,' 3.  TOTAL ANNUAL COST, $/MG',9X,2(F10.2,8X),
     4          /25X,' 4.  ENERGY CONSUMED, KWH/MG',9X,2(F10.2,8X))
          WRITE(IO,135)(W(K),RHS(K),K=5,8)
 135      FORMAT(25X,' 5.  ENERGY PRODUCED, KWH/MG',9X,2(F10.2,8X),
     2          /25X,' 6.  NET ENERGY CONSUMED, KWH/MG',5X,2(F10.2,8X),
     3          /25X,' 7.  LAND REQUIRED, ACRES',12X,2(F10.2,8X),
     4          /25X,' 8.  UNDESIREABILITY INDEX',11X,2(F10.2,8X))
C
          WRITE(IO,200)
 200      FORMAT(////51X,'ECONOMIC DATA'/51X,13('_')//)
          WRITE(IO,210) CCI,WPI,DHR,PCT
 210      FORMAT(33X,' CONSTRUCTION COST INDEX',12X,F12.4/
     2           33X,' WHOLESALE PRICE INDEX',14X,F12.4/
     3           33X,' DIRECT HOURLY WAGE, $/HR',11X,F12.4/
     4           33X,' FRACTION CHARGED TO SUPERVISION',4X,F12.4)
```

```
      WRITE(IO,220) RATIO,CKWH,CF,RI,AF
220   FORMAT(33X,' COST ESCALATOR FOR MISC. FEES',6X,F12.4/
     2        33X,' COST OF ELECTRICITY, $/KWH',9X,F12.4/
     3        33X,' FUEL CONVERSION EFFICIENCY',9X,F12.4/
     4        33X,' DISCOUNT RATE',22X,F12.4/
     5        33X,' CAPITAL RECOVERY FACTOR',12X,F12.4)
      CCI=CCI/1.506
      WPI=WPI/1.122
C
C             INITIALIZE TARGET VALUES OF CRITERIA LIMITS
C
      TEPMAX=0.
      DO 160 J=1,NTPS
160   TEPMAX=TEPMAX+EEPMAX(J)
      RHS(5)=TEPMAX-RHS(5)
      RHS(6)=TEPMAX+RHS(6)
C
C             READ IN # NEXT BEST DESIGNS WANTED WITHIN 'FACTR' OF
C             OPTIMAL DESIGN.
C
      READ(INP,4) KMAX,FACTR
      FACTR=1.+FACTR
C
C             IF SYSTEM DESIGN IS TO BE FIXED, READ IN PROCESS UNIT NOS.
C             AND FIND MIXING STAGE FOR SECONDARY AND PRIMARY SLUDGES.
C
      READ(INP,2,END=80)(IPOPT(J),J=1,NTPS)
      ISW=1
      JT=JSTRM(4)
      JMIX=JSTRM(5)+NSSPS
70    IF (IP(IPOPT(JT)) .NE. 0) GO TO 80
      JMIX=JMIX-1
      JT=JT-1
      IF (JT .GT. JSTRM(2)) GO TO 70
      JMIX=JSTRM(5)
80    RETURN
1     FORMAT(8F10.0)
2     FORMAT(8I10)
3     FORMAT(3I10,2F10.0)
4     FORMAT(I10,F10.0)
      END
C
C
C             OUTPUT SUBROUTINE
C
      SUBROUTINE OUTPUT(ISW)
C
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     2        INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     3        ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     4        CF,EER,EEP,ALAND
      COMMON/PROC/ NPROC(20),KPROC(10,20),NWPS,NPSPS,NSSPS,
     2             NTPS,NTPU,JSTRM(22),JSIDE(20),P(20,10),
     3             IPOPT(20),PINFLO(20),EFFSTD(20),ISC(45),IDC(45)
      COMMON/COST/ C(20,10),CP(10),RHS(10),W(10),UDR(50),
     2             IPSAVE(40,20),JMSAVE(40),TEPMAX,KMAX,FACTR,TUPE
     3             ,EEPMAX(20)
      DIMENSION CTOT(10)
C
C
      JMIX=JSTRM(21)
      WRITE(IO,20) (I,I=1,8)
20    FORMAT(//' STAGE  PROCESS  SLUDGE,',38X,'SELECTION CRITERIA'/
     2         ' NO.   OPTION   TONS/DAY',2X,8(6X,I1,4X)/
     3        1X,5('_'),2X,7('_'),2X,8('_'),2X,8(2X,9('_')))
```

```
      STOT=0.
      DO 30 K=1,10
30    CTOT(K)=0.
C
      DO 120 J=1,NTPS
      SMIX=' '
      N=IPOPT(J)
      IPROC=IP(N)
      IF(IPROC.EQ.0)GO TO 110
      IF(J.GT.JSTRM(2))GO TO 50
      OS2=NTPS+J
      S2=SMATX(2,OS2)*SMATX(10,OS2)*8.33/2000.
      STOT=STOT+S2
      GO TO 60
C
50    S2=SMATX(2,J)*SMATX(10,J)*8.33/2000.
C
60    IF(J.EQ.JMIX)SMIX='*'
      WRITE(IO,90) J,SMIX,N,S2,(C(J,K),K=1,8)
90    FORMAT(2X,I2,A1,5X,I2,5X,F8.2,2X,8F11.2)
C
      DO 95 K=1,10
95    CTOT(K)=CTOT(K)+C(J,K)
      GO TO 120
110   IF(J.EQ.JMIX)JMIX=JMIX+1
120   CONTINUE
      WRITE(IO,130)
130   FORMAT(17X,8('_'),2X,8(2X,9('_')))
      WRITE(IO,140)STOT,(CTOT(K),K=1,8)
140   FORMAT(' SYSTEM VALUES    ',F8.2,2X,8F11.2)
      IF (ISW .EQ.0) GO TO 145
      WRITE(IO,190)
190   FORMAT(////40X,'PROCESS PERFORMANCE CHARACTERISTICS'/40X,35('_')
     2 //49X,'VOLUME FLOW, MGD'/49X,'CONCENTRATION, MG/L'/15X,
     4 'CONSULT PROGRAM REFERENCE MANUAL FOR MEANING OF PROCESS INPUT',
     5 ' AND OUTPUT DESIGN DATA.'//)
      DO 260 J=1,NTPS
      N=IPOPT(J)
      IPROC=IP(N)
      IF(IPROC.EQ.0)GO TO 260
      IS1=J
      OS1=J+1
      IF(J.EQ.JSTRM(2))OS1=JSTRM(15)
      IF(J.EQ.JSTRM(4))OS1=JSTRM(16)
      IF(J.EQ.JSTRM(6))OS1=JSTRM(17)
      OS2=NTPS+J
      WRITE(IO,200) J,N
200   FORMAT(//46X,'STAGE ',I2,'   PROCESS OPTION ',I2/46X,28('_'))
      WRITE(IO,210)
210   FORMAT(/51X,'INPUT DESIGN DATA:')
      WRITE(IO,220) (DMATX(I,N),I=1,16)
220   FORMAT(8F12.3)
      WRITE(IO,230)
230   FORMAT(/51X,'OUTPUT DESIGN DATA:')
      WRITE(IO,240) (OMATX(I,N),I=1,20)
240   FORMAT(9F12.3)
      WRITE(IO,250)
250   FORMAT(/35X,'INFLUENT - EFFLUENT - SIDESTREAM CHARACTERISTICS:'/
     2   9X,'Q',9X,'SOC',8X,'SNBC',9X,'SON',9X,'SOP',9X,
     3   'SFM',8X,'SBOD',9X,'VSS',9X,'TSS')
      WRITE(IO,240) (SMATX(I,IS1),I=2,10),(SMATX(I,OS1),I=2,10),
     2                (SMATX(I,OS2),I=2,10)
      WRITE(IO,255)
255   FORMAT(7X,'DOC',8X,'DNBC',10X,'DN',10X,'DP',9X,'DFM',9X,'ALK',
     2        8X,'DBOD',9X,'NH3',9X,'NO3')
      WRITE(IO,240) (SMATX(I,IS1),I=11,19),(SMATX(I,OS1),I=11,19),
     2                (SMATX(I,OS2),I=11,19)
```

```
260     CONTINUE
145     RETURN
        END
C
C
C
C                       SYSTEM SOLUTION SUBROUTINE
        SUBROUTINE SOLVE(TCS,CSIM,NITER)
C.
        INTEGER OS1,OS2
        COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     2         INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     3         ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     4         CF,FER,EEP,ALAND
        COMMON/PROC/ NPROC(20),KPROC(10,20),NWPS,NPSPS,NSSPS,
     2               NTPS,NTPU,JSTRM(22),JSIDE(20),P(20,10),
     3               IPOPT(20),PINFLO(20),EFFSID(20),ISC(45),IDC(45)
        COMMON/COST/ C(20,10),CP(10),RHS(10),W(10),UDM(50),
     2               IPSAVE(40,20),JMSAVE(40),IEPMAX,KMAX,FACTR,TUPE
     3               ,EEPMAX(20)
        DIMENSION CSIM(10),TRECYC(20),RECYC(20)
        DATA NITMAX/20/,EPS1/.001/,EPS2/.0001/
C
        DO 5 I=1,20
5       RECYC(I)=0.
        DELSUM=0.
        NITER=0
C
C               EVALUATE TOTAL SYSTEM PERFORMANCE WITH CURRENT VALUE
C               OF RECYCLE FLOW
C
90      NITER=NITER+1
        IF(NITER.GT.NITMAX) GO TO 100
        DO 10 I=1,20
        TRECYC(I)=RECYC(I)
10      SMATX(I,1)=PINFLO(I)
        SUMOLD=DELSUM
        CALL SYSTEM(TCS,CSIM,RECYC)
C
C               MIX RECYCLE FLOWS OFF OF SLUDGE UNITS TOGETHER
C
C       THE VALUE OF J SHOULD BE SET TO THE DIMENSION OF THE SECOND
C       INDEX OF SMATX(I,J).
35      J=45
        J1=JSTRM(3)
        J2=JSTRM(6)
        J3=JSTRM(20)
        CALL SMIX(J,J1,J2,J3)
        DO 40 I=2,20
40      RECYC(I)=SMATX(I,J)
C
C               CHECK FOR CONVERGENCE
C
        ISTOP=1
        DELSUM=0.
        DO 50 I=2,20
        DEL=ABS(RECYC(I)-TRECYC(I))
        DELSUM=DELSUM+DEL
        IF(DEL.GT.EPS1*RECYC(I)) ISTOP=0
50      CONTINUE
        IF(ABS(DELSUM-SUMOLD).LT.EPS2*DELSUM) GO TO 100
        IF(ISTOP.EQ.1) GO TO 100
        GO TO 90
C
C               CONVERGENCE IS ATTAINED.
C
100     RETURN
        END
```

```
C
C
C                OPTIMIZATION SUBROUTINE
C
C         IMPLICIT ENUMERATION OPTIMIZATION PROCEDURE
C
          SUBROUTINE OPTIM(NPHASE,LIMIT,FACTOR,FMIN,PMIN,IFEAS)
C
          INTEGER OS1,OS2
          COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     1            INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     2            ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     3            CF,EER,EEP,ALAND
          COMMON/PROC/ NPROC(20),KPROC(10,20),NWPS,NPSPS,NSSPS,
     2                 NTPS,NTPU,JSTRM(22),JSIDE(20),P(20,10),
     3                 IPOPT(20),PINFLO(20),EFFSTD(20),ISC(45),IDC(45)
          COMMON/COST/ C(20,10),CP(10),RHS(10),W(10),UDR(50),
     2                IPSAVE(40,20),JMSAVE(40),TEPMAX,KMAX,FACTR,TUPE
     3                ,EEPMAX(20)
          DIMENSION LSAVE(20),FSAVE(40),IPMIN(20)
          DIMENSION FTEMP(10),PTEMP(10),FJ(20,10),PJ(20,10)
          EQUIVALENCE (JLEFF,JSTRM(15)),(JSSEFF,JSTRM(16)),
     2               (JPSEFF,JSTRM(17)),(JMIX,JSTRM(21))
C
C
C                BEGIN AT STAGE J = 1
C
          IFEAS=0
          KOUNT=0
          DO 5 K=1,10
          FJ(1,K)=0.
5         PJ(1,K)=0.
          JSTART=1
          JMIX=JPSEFF
C
C                FIND NEXT OPTION IN PROCESS LIST AT STAGE J
C
15        J=JSTART
20        L=1
25        LSAVE(J)=L
          N=KPROC(L,J)
          IPROC=IP(N)
          IS1=J
          IS2=0
          OS1=J+1
          IF(J.EQ.JSTRM(2))OS1=JLEFF
          IF(J.EQ.JSTRM(4))OS1=JSSEFF
          IF(J.EQ.JSTRM(6))OS1=JPSEFF
          OS2=NTPS+J
          IF(J.EQ.JSTRM(3))GO TO 30
          IF(J.EQ.JSTRM(5))GO TO 40
          GO TO 60
C
C                J=START OF SECONDARY SLUDGE PROCESSING.
C                MIX SECONDARY SLUDGE STREAMS TOGETHER.
C
30        J1=JSTRM(1)
          J2=JSTRM(2)
          CALL SMIX(J,J1,J2,J)
          IDC(J)=1
          ISC(J)=0
          IF (SMATX(2,J) .GT. 0.) ISC(J)=2
          GO TO 80
C
C                J=START OF PRIMARY SLUDGE PROCESSING.
C                MIX PRIMARY SLUDGE STREAMS TOGETHER.
C                FIND MIXING POINT OF PRIMARY AND
C                SECONDARY SLUDGES (JMIX).
```

```
C
 40      J1=JSTRM(1)
         J2=JSTRM(2)
         CALL SMIX(J,J1,J2,J)
         IDC(J)=1
         ISC(J)=0
         IF (SMATX(2,J) .GT. 0.) ISC(J)=1
 45      JT=JSTRM(4)
         JMIX=JSTRM(5)+NSSPS
 50      IF(IP(IPOPT(JT)).NE.0)GO TO 60
         JMIX=JMIX-1
         JT=JT-1
         IF(JT.GT.JSTRM(2))GO TO 50
         JMIX=JSTRM(5)
         IF (J .EQ. JMIX) GO TO 65
C
 60      IF(J.NE.JMIX .OR. L .GT. 1)GO TO 80
C
C               J=JMIX, MIX PRIMARY AND SECONDARY SLUDGES TOGETHER.
C
 65      TEMP1=SMATX(2,JSSEFF)+SMATX(2,J)
         DO 70 I=3,20
         TEMP2=SMATX(2,J)*SMATX(I,J)+SMATX(2,JSSEFF)*SMATX(I,JSSEFF)
 70      SMATX(I,J)=TEMP2/TEMP1
         SMATX(2,J)=TEMP1
         ISC(J)=ISC(J)+ISC(JSSEFF)
         IF (ISC(J) .EQ. 2) IDC(J)=IDC(JSSEFF)
         IF (ISC(J) .EQ. 3) IDC(J)=10*IDC(J)+IDC(JSSEFF)
C
C               EVALUATE SELECTION CRITERIA FOR CURRENT PROCESS AND ADD
C               TO SYSTEM VALUES. CHECK IF CONSTRAINTS ARE MET AND
C               CURRENT UPPER BOUND NOT EXCEEDED.
C
 80      CONTINUE
         CALL UNIT(J,IPROC)
         PSUM=0.
         FSUM=0.
         DO 85 K=1,10
         FTEMP(K)=FJ(J,K)+C(J,K)
         PTEMP(K)=PJ(J,K)+CP(K)
         IF(K.EQ.5)FTEMP(K)=FJ(J,K)+EEPMAX(J)-C(J,K)
         IF(K.EQ.6)FTEMP(K)=FJ(J,K)+EEPMAX(J)+C(J,K)
         IF(FTEMP(K)+PTEMP(K).GT.RHS(K))GO TO 90
 75      FSUM=FSUM+W(K)*FTEMP(K)
         PSUM=PSUM+W(K)*PTEMP(K)
 85      CONTINUE
         IF(FACTOR*FMIN.LE.FSUM+PSUM)GO TO 90
C
C               ADD CURRENT PROCESS ALTERNATIVE TO SOLUTION AND UPDATE
C               SYSTEM CRITERIA VALUES.
C
         IPOPT(J)=N
         J=J+1
         DO 95 K=1,10
         FJ(J,K)=FTEMP(K)
 95      PJ(J,K)=PTEMP(K)
         IF(J.LE.NTPS)GO TO 20
C
C               NEW TOTAL SYSTEM WAS ARRIVED AT. UPDATE UPPER BOUND.
C
         IFEAS=1
         FTOT=FSUM+PSUM
         IF(FTOT.GE.FMIN)GO TO 105
         FMIN=FTOT
         PMIN=PSUM
```

```
      JMMIN=JMIX
      DO 100 J=1,NTPS
100   IPMIN(J)=IPOPT(J)
C
C             IF THIS IS SENSITIVITY PHASE, INSERT NEW SOLUTION INTO LIST
C
105   IF(NPHASE.EQ.1)GO TO 180
      IF(KOUNT.EQ.0)GO TO 120
C
C        LOCATE POSITION OF LARGEST ENTRY IN LIST
      FMAX=0.
      DO 110 M=1,KOUNT
      IF(FTOT.EQ.FSAVE(M))GO TO 180
      IF(FSAVE(M).LE.FMAX)GO TO 110
      FMAX=FSAVE(M)
      KFMAX=M
110   CONTINUE
      IF(FTOT.GE.FMAX)GO TO 140
      IF(KOUNT.EQ.LIMIT)GO TO 130
C
C        LENGTH OF LIST IS LESS THAN LIMIT
120   KIN=KOUNT+1
      KOUNT=KIN
      GO TO 160
C
C        LENGTH OF LIST EQUALS LIMIT. REPLACE LARGEST ENTRY WITH
C        NEW SOLUTION.
130   KIN=KFMAX
      GO TO 160
C
C        NEW SOLUTION IS LARGER THAN LARGEST ENTRY IN LIST. IF LENGTH
C        OF LIST EQUALS LIMIT, REJECT NEW SOLUTION.
140   IF(KOUNT.EQ.LIMIT)GO TO 180
      FMAX=FTOT
      KFMAX=KOUNT+1
      GO TO 120
C
C        PLACE NEW SOLUTION INTO LIST.
160   FSAVE(KIN)=FTOT
      DO 170 J=1,NTPS
170   IPSAVE(KIN,J)=IPOPT(J)
      JMSAVE(KIN)=JMIX
180   CONTINUE
C
C
      J=NTPS
C
C             MOVE TO NEXT PROCESS OPTION AT CURRENT STAGE
C             IF NO MORE OPTIONS THEN MOVE BACK ONE STAGE
90    L=LSAVE(J)+1
      IF(L.LE.NPROC(J))GO TO 25
      J=J-1
      IF(J.GE.JSTART)GO TO 90
C
C             IF CANNOT MOVE BACK ANY MORE STAGES THEN STOP THE SEARCH
C
      JMIX=JMMIN
      DO 190 J=1,NTPS
190   IPOPT(J)=IPMIN(J)
      LIMIT=KOUNT
      RETURN
      END
C
C
```

```
C
C             SYSTEM EVALUATION SUBROUTINE
C
C
      SUBROUTINE SYSTEM(TCS,F,RECYC)
C
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMAIX(20,50),IP(50),
     1       INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     2       ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     3       CF,EER,EEP,ALAND
      COMMON/PROC/ NPROC(20),KPROC(10,20),NWFS,NPSPS,NSSPS,
     2             NTPS,NTPU,JSTRM(22),JSIDE(20),P(20,10),
     3             IPOPT(20),PINFLO(20),EFFSID(20),ISC(45),IDC(45)
      COMMON/COST/ C(20,10),CP(10),RHS(10),W(10),UDR(50),
     2             IPSAVE(40,20),JMSAVE(40),IEPMAX,KMAX,FACTR,TUPE
     3             ,EEPMAX(20)
      DIMENSION F(10),RECYC(20)
      EQUIVALENCE (JLEFF,JSTRM(15)),(JSSEFF,JSTRM(16)),(JPSEFF,
     2            JSTRM(17)),(JRECYC,JSTRM(20)),(JMIX,JSTRM(21))
C
      TCS=0.
      DO 5 K=1,10
5     F(K)=0.
C
C             EVALUATE SELECTION CRITERIA FOR THE PROCESS SELECTED
C             AT EACH STAGE.
C
      DO 90 J=1,NTPS
      N=IPOPT(J)
      IPROC=IP(N)
      IS1=J
      IS2=0
      OS1=J+1
      IF(J.EQ.JSTRM(2))OS1=JLEFF
      IF(J.EQ.JSTRM(4))OS1=JSSEFF
      IF(J.EQ.JSTRM(6))OS1=JPSEFF
      OS2=NTPS+J
      IF(J.EQ.JRECYC)GO TO 10
      IF(J.EQ.JSTRM(3))GO TO 30
      IF(J.EQ.JSTRM(5))GO TO 40
      GO TO 60
C
C             J=RECYCLE MIXING POINT. MIX INFLUENT AND RECYCLE STREAMS.
C
10    TEMP1=SMATX(2,J)+RECYC(2)
      DO 20 I=3,20
      TEMP2=SMATX(2,J)*SMATX(I,J)+RECYC(2)*RECYC(I)
20    SMATX(I,J)=TEMP2/TEMP1
      SMATX(2,J)=TEMP1
      SMATX(1,J)=1.
      SMATX(20,J)=0.
      GO TO 80
C
C             J=START OF SECONDARY SLUDGE PROCESSING.
C             MIX SECONDARY SLUDGE STREAMS TOGETHER.
C
30    J1=JSTRM(1)
      J2=JSTRM(2)
      CALL SMIX(J,J1,J2,J)
      IDC(J)=1
      ISC(J)=0
      IF (SMATX(2,J) .GT. 0.) ISC(J)=2
      GO TO 80
C
C             J=START OF PRIMARY SLUDGE PROCESSING.
C             MIX PRIMARY SLUDGE STREAMS TOGETHER.
C
```

```
40        J1=JSTRM(1)
          J2=JSTRM(2)
          CALL SMIX(J,J1,J2,J)
          IDC(J)=1
          ISC(J)=0
          IF (SMATX(2,J) .GT. 0.) ISC(J)=1
60        IF(J.NE.JMIX)GO TO 80
C
C                 J=MIXING POINT OF PRIMARY AND SECONDARY SLUDGES.
C
          TEMP1=SMATX(2,JSSEFF)+SMATX(2,J)
          DO 70 I=3,20
          TEMP2=SMATX(2,JSSEFF)*SMATX(I,JSSEFF)+SMATX(2,J)*SMATX(I,J)
70        SMATX(I,J)=TEMP2/TEMP1
          SMATX(2,J)=TEMP1
          ISC(J)=ISC(J)+ISC(JSSEFF)
          IF (ISC(J) .EQ. 2) IDC(J)=IDC(JSSEFF)
          IF (ISC(J) .EQ. 3) IDC(J)=10*IDC(J)+IDC(JSSEFF)
C
C                 DETERMINE PERFORMANCE OF PROCESS N AT STAGE J.
C
80        CALL UNIT(J,IPROC)
          DO 85 K=1,10
          IF(K.EQ.5)GO TO 81
          IF(K.EQ.6)GO TO 82
          F(K)=F(K)+C(J,K)
          GO TO 85
81        F(K)=F(K)+EEPMAX(J)-C(J,K)
          GO TO 85
82        F(K)=F(4)+F(5)
85        CONTINUE
90        CONTINUE
          DO 95 K=1,10
95        TCS=TCS+W(K)*F(K)
          RETURN
          END
C
C
C                 UNIT PROCESS EVALUATION SUBROUTINE
C
          SUBROUTINE UNIT(J,IPROC)
C
          INTEGER OS1,OS2
          COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     1            INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     2            ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     3            CF,EER,EEP,ALAND
          COMMON/PROC/ NPROC(20),KPROC(10,20),NWPS,NPSPS,NSSPS,
     2                 NTPS,NTPU,JSTRM(22),JSIDE(20),P(20,10),
     3                 IPOPT(20),PINFLO(20),EFFSTD(20),ISC(45),IDC(45)
          COMMON/COST/ C(20,10),CP(10),RHS(10),W(10),UDR(50),
     2                 IPSAVE(40,20),JMSAVE(40),IEPMAX,KMAX,FACTR,TUPE
     3                 ,EEPMAX(20)
          COMMON/TABLES/ VACF1(3,5,5),VACF5(3,5,5),VACF6(3,5,5),VACF9(3,5,5)
     2         ,CENT1(3,5,5),CENT2(3,5,5),CENT5(3,5,5),CENT7(3,5,5)
          DIMENSION SAVE(20)
          EQUIVALENCE (J2LP,JSTRM(2)),(JLEFF,JSTRM(15)),
     2     (JMIX,JSTRM(21)),(JSSEFF,JSTRM(16))
C
          TUPE=TUPE+1.
C
C                 INITIALIZE ERROR INDICATOR
C
          IAERF=0
```

```
C                INITIALIZE OUTPUT STREAMS AND SELECTION CRITERIA
C
        ISC(OS1)=ISC(IS1)
        IDC(OS1)=IDC(IS1)
        DO 5 I=1,20
        SMATX(I,OS1)=SMATX(I,IS1)
5       SMATX(I,OS2)=0.
        DO 15 II=1,5
        CCOST(II)=0.
        COSTO(II)=0.
        ACOST(II)=0.
15      CONTINUE
        DO 16 K=1,10
        CP(K)=0.
16      C(J,K)=0.
        EEP=0.
        EEP=0.
        ALAND=0.
C
C                DETERMINE WHICH PROCESS SUBROUTINE TO CALL
C
        IF(IPROC.EQ.0)GO TO 560
        IF(SMATX(2,IS1).EQ.0.)GO TO 560
        GO TO(10,20,30,560,560,60,70,80,90,100,110,120,130,140,150,160,
      1      170,180,560,560,560,220,230,240,250,260),IPROC
        GO TO 560
C
C                PRELIMINARY TREATMENT
C
10      CALL PREL
        GO TO 500
C
C                PRIMARY SEDIMENTATION
C
20      CALL PRSET
        GO TO 500
C
C                ACTIVATED SLUDGE
C
30      IF (DMATX(1,N) .GT. .75*(SMATX(8,IS1)+SMATX(17,IS1)))
      2    GO TO 225
        CALL AERFS
        IF(IAERF)500,500,225
C
C                ANAEROBIC DIGESTION
C
60      CALL DIG
C
C          UPDATE SLUDGE DIGESTION CODE
        IDC(OS1)=3
        GO TO 500
C
C                VACUUM FILTRATION
C
C         DETERMINE SLUDGE TYPE
70      I1=ISC(IS1)
C
C         DETERMINE TYPE OF STABILIZATION
        GO TO (71,71,73),I1
71      J1=IDC(IS1)
        J2=J1
        W1=1.
        W2=0.
        GO TO 74
73      IF(IDC(IS1).LT.10)GO TO 71
        J1=IDC(IS1)/10
        J2=IDC(JSSEFF)
```

Reproduced from
best available copy.

```
      TEMP1=SMATX(2,JMIX)*SMATX(10,JMIX)
      TEMP2=SMATX(2,JSSEFF)*SMATX(10,JSSEFF)
      W2=TEMP2/TEMP1
      W1=1.-W2
C
C       DETERMINE PROCESS PARAMETERS
74    L=DMATX(11,N)
      DMATX(1,N)=W1*VACF1(I1,J1,L)+W2*VACF1(I1,J2,L)
      DMATX(5,N)=W1*VACF5(I1,J1,L)+W2*VACF5(I1,J2,L)
      DMATX(6,N)=W1*VACF6(I1,J1,L)+W2*VACF6(I1,J2,L)
      DMATX(9,N)=W1*VACF9(I1,J1,L)+W2*VACF9(I1,J2,L)
      CALL VACF
      GO TO 500
C
C              GRAVITY THICKENING
C
C       SAVE SECONDARY INFLUENT STREAM
80    IF(IS2.EQ.0)GO TO 82
      DO 81 I=2,20
81    SAVE(I)=SMATX(I,IS2)
C
C       DETERMINE SLUDGE TYPE
82    I1=ISC(IS1)
C
C       DETERMINE UNDERFLOW SOLIDS CONC. AND LOADING
      DMATX(2,N)=DMATX(4+I1,N)
      DMATX(4,N)=DMATX(7+I1,N)
      IF(DMATX(2,N).LT.SMATX(10,IS1))GO TO 560
      CALL THICK
      IF(IS2.EQ.0)GO TO 500
      DO 83 I=2,20
83    SMATX(I,IS2)=SAVE(I)
      GO TO 500
C
C              ELUTRIATION
C
C       SAVE FLOW OF SECOND INFLUENT STREAM
90    IS2=JLEFF
      SAVE(2)=SMATX(2,IS2)
C
C        DETERMINE SLUDGE TYPE
      I1=ISC(IS1)
C
C        DETERMINE UNDERFLOW CONC. AND LOADING
      DMATX(2,N)=DMATX(5+I1,N)
      DMATX(5,N)=DMATX(8+I1,N)
C
C       DO NOT ALLOW ELUTRIATION IF PRECEEDED BY LIME STABILIZATION
      IF(IDC(IS1).EQ.2)GO TO 225
      IF(IDC(IS1)/10.EQ.2)GO TO 225
      IF(IDC(JSSEFF).EQ.2)GO TO 225
      CALL ELUT
      SMATX(2,IS2)=SAVE(2)
      IDC(OS1)=4
      GO TO 500
C
C              SAND DRYING BEDS
C
C        CHECK TO SEE IF SLUDGE IS STABILIZED
100   IF (IDC(IS1) .LE. 1) GO TO 225
      IF (IDC(IS1) .LT.10) GO TO 105
      IF (IDC(IS1)/10 .LE. 1) GO TO 225
      IF (IDC(JSSEFF) .LE. 1)  GO TO 225
105   CONTINUE
```

```
C          CHECK THAT MINIMUM INFLUENT SOLIDS CONC. IS MET
         IF(SMATX(10,IS1)/10000..LT.1.12)GO TO 225
C
C           FIND COST OF SLUDGE HOLDING TANKS
         SAVE(1)=DMATX(1,N)
         SAVE(16)=DMATX(16,N)
         DMATX(1,N)=DMATX(6,N)
         DMATX(16,N)=DMATX(7,N)
         CALL SHT
         CCOST(2)=CCOST(1)
         COSTO(2)=COSTO(1)
         DMATX(1,N)=SAVE(1)
         DMATX(16,N)=SAVE(16)
C
C           DETERMINE SLUDGE TYPE
         I1=ISC(IS1)
C
C           DETERMINE CAKE SOLIDS CONC.
         DMATX(1,N)=DMATX(2+I1,N)
         CALL SBEDS
C
C           FIND COST OF LAND
         CCOST(3)=DMATX(8,N)*ALAND
         GO TO 500
C
C                 TRICKLING FILTER
C
110      IF (DMATX(1,N) .GT. .75*(SMATX(8,IS1)+SMATX(17,IS1)))
     2      GO TO 225
         CALL TRFS
         IF (IAERF .GT. 0) GO TO 225
         GO TO 500
C
C                 CHLORINATION
C
120      CALL CHLOR
         GO TO 500
C
C                 FLOTATION THICKENING
C
130      IF(IS2.GT.0)SAVE(2)=SMATX(2,IS2)
         CALL TFLOT
         IF(IS2.GT.0)SMATX(2,IS2)=SAVE(2)
         GO TO 500
C
C                 INCINERATION
C
140      CALL MHINC
         DO 145 I=1,20
145      SMATX(I,OS1)=0.
         GO TO 500
C
C                 RAW WASTEWATER PUMPING
C
150      CALL RWP
         GO TO 500
C
C                 SLUDGE HOLDING TANKS
C
160      CALL SHT
         GO TO 500
C
C                 CENTRIFUGATION
C
C        DETERMINE SLUDGE TYPE
170      I1=ISC(IS1)
```

```
C
C         DETERMINE TYPE OF STABILIZATION
        GO TO (171,171,173),I1
 171    J1=IDC(IS1)
        J2=J1
        W1=1.
        W2=0.
        GO TO 174
 173    IF(IDC(IS1).LT.10)GO TO 171
        J1=IDC(IS1)/10
        J2=IDC(JSSEFF)
        TEMP1=SMATX(2,JMIX)*SMATX(10,JMIX)
        TEMP2=SMATX(2,JSSEFF)*SMATX(10,JSSEFF)
        W2=TEMP2/TEMP1
        W1=1.-W2
C
C         DETERMINE PROCESS PARAMETERS
 174    L=DMATX(9,N)
        DMATX(1,N)=W1*CENT1(I1,J1,L)+W2*CENT1(I1,J2,L)
        TEMP=W1*CENT2(I1,J1,L)+W2*CENT2(I1,J2,L)
        DMATX(2,N)=TEMP*1.E4
        DMATX(5,N)=W1*CENT5(I1,J1,L)+W2*CENT5(I1,J2,L)
        DMATX(7,N)=W1*CENT7(I1,J1,L)+W2*CENT7(I1,J2,L)
        CALL CENT
        GO TO 500
C
C              AEROBIC DIGESTION
C
C          FIND SRT OF ACTIVATED SLUDGE UNIT
 180    DO 183 J1=1,J2LP
        L=IP(IPOPT(J1))
        IF(L.EQ.3)GO TO 185
        IF(L.EQ.25)GO TO 185
 183    CONTINUE
        DMATX(3,N)=0.
        GO TO 186
 185    DMATX(3,N)=DMATX(2,IPOPT(J1))
 186    CONTINUE
        CALL AEROB
C
C         UPDATE SLUDGE STABILIZATION CODE
        IDC(OS1)=3
        GO TO 500
C
C              LAND DISPOSAL
C
 220    IF(DMATX(6,N).EQ.1)GO TO 227
C
C         CHECK TO SEE THAT SLUDGE IS STABILIZED
        IF (IDC(IS1) .LE. 1) GO TO 225
        IF (IDC(IS1) .LT.10) GO TO 228
        IF (IDC(IS1)/10 .LE. 1) GO TO 225
        IF (IDC(JSSEFF) .LE. 1) GO TO 225
        GO TO 228
C
C          CHECK THAT SOLIDS IS OVER 15% IF LANDFILLING
 227    TEMP=SMATX(10,IS1)*1.E-6
        IF(TEMP.LT.0.15)GO TO 225
C
C          CHECK IF FINAL DISPOSAL INCURS ANY COST
 228    IF(DMATX(16,N).EQ.0.)GO TO 560
        CALL LANDD
```

Reproduced from
best available copy.

```
      DO 229 I=1,20
229   SMATX(I,OS1)=0.
      GO TO 500
C
C       INFEASIBLE OPTION. MAKE OBJECTIVE VALUE VERY HIGH.
225   DO 226 K=1,10
226   C(J,K)=100.E20
      C(J,5)=0.
      RETURN
C
C             LIME STABILIZATION
C
230   CALL LIME
C
C       ADJUST SLUDGE STABILIZATION CODE
      IDC(OS1)=2
      GO TO 500
C
C             ROTATING BIOLOGICAL CONTACTOR
C
240   CALL RBC
      GO TO 500
C
C             PRIMARY SEDIMENTATION - ACTIVATED SLUDGE - WASTE
C             ACTIVATED SLUDGE RETURNED TO PRIMARY SETTLER
C
250   CALL PSASFS
      IF(IAERF.GT.0)GO TO 225
      GO TO 500
C
C             HEAT TREATMENT
C
C        FIND COST OF HOLDING TANK
260   IF(DMATX(8,N).EQ.0.)GO TO 261
      SAVE(1)=DMATX(1,N)
      SAVE(16)=DMATX(16,N)
      DMATX(1,N)=DMATX(8,N)
      DMATX(16,N)=DMATX(9,N)
      CALL SHT
      CCOST(3)=CCOST(1)
      COSTO(3)=COSTO(1)
      DMATX(1,N)=SAVE(1)
      DMATX(16,N)=SAVE(16)
C
C        CHECK IF SLUDGE DIGESTED AND FIND STREAM NOS. AT MIXING POINT
261   DMATX(3,N)=0.
      IF(IDC(IS1).EQ.3) DMATX(3,N)=1.
      I1=JMIX
      I2=JSSEFF
      IF(J.GE.JMIX)GO TO 262
      I1=J
      I2=0
      IF(J.GE.JSTRM(5))GO TO 262
      I1=0
      I2=0
262   DMATX(1,N)=I1
      DMATX(2,N)=I2
C
C        FIND COST OF THERMAL REACTOR
      CALL HEAT
C
      IDC(OS1)=5
      GO TO 500
C
```

```
C
C               SUM SUB-UNIT AMORTIZATION AND O&M COSTS.
C
500     DO 540 II=1,5
        CCOST(II)=CCOST(II)*CCI*RATIO
        COSTO(II)=COSTO(II)*RATIC
        IF(ACOST(II))520,510,520
510     ACOST(II)=CCOST(II)*AF/(3650.*PINFLO(2))
        GO TO 530
520     ACOST(II)=ACOST(II)*CCI*RATIO
530     C(J,3)=C(J,3)+ACOST(II)+COSTO(II)
        C(J,1)=C(J,1)+CCOST(II)
        C(J,2)=C(J,2)+COSTO(II)
540     CONTINUE
C
C               EVALUATE SELECTION CRITERIA
C
        C(J,1)=C(J,1)/1,E6
        C(J,2)=C(J,2)*10.
        C(J,3)=C(J,3)*10.
        C(J,4)=EER/PINFLO(2)
        C(J,5)=EEP/PINFLO(2)
        C(J,6)=C(J,4)-C(J,5)
        C(J,7)=ALAND
        C(J,8)=UDR(N)
C
C               EVALUATE PENALTIES FOR EACH CRITERION
C
        IF(J.LE.J2LP)GO TO 600
        DO 555 K=1,10
        CP(K)=P(2,K)*SMATX(2,OS2)
        TEMP1=SMATX(2,OS2)
        DO 550 I=3,19
        TEMP2=SMATX(I,OS2)
        IF(I.EQ.9)TEMP2=SMATX(9,OS2)-SMATX(3,OS2)-SMATX(5,OS2)-SMATX(6,OS2)
        IF(I.EQ.13)TEMP2=SMATX(13,OS2)-SMATX(18,OS2)-SMATX(19,OS2)
        IF(TEMP2.LE.0.)TEMP2=0.
550     CP(K)=CP(K)+(P(I,K)*TEMP1*TEMP2)
555     CONTINUE
        GO TO 600
C
C               PROCESS IS NULL PROCESS WITH ZERO COST
C
560     DO 570 I=1,20
        SMATX(I,OS1)=SMATX(I,IS1)
570     SMATX(I,OS2)=0.
        N=JSTRM(22)
        GO TO 600
C
C               CHECK EFFLUENT STANDARDS ON BOD, TSS, TKN, NO3, AND P
C
600     IF(J.NE.J2LP)RETURN
        IF(SMATX(8,JLEFF)+SMATX(17,JLEFF).GT.EFFSTD(1))GO TO 225
        IF(SMATX(10,JLEFF).GT.EFFSTD(2))GO TO 225
        IF(SMATX(5,JLEFF)+SMATX(18,JLEFF).GT.EFFSTD(3))GO TO 225
        IF(SMATX(10,JLEFF).GT.EFFSTD(4))GO TO 225
        IF(SMATX(14,JLEFF).GT.EFFSTD(5))GO TO 225
        RETURN
        END
C
```

```
C               PENALTY SUBROUTINE
C
C
C
          SUBROUTINE PNALTY(CSIM)
C
          COMMON SMATX(20,45),DUMMY1(2000),IDUMMY(58),
     2          DUMMY2(27)
          COMMON/PROC/ ID(225),JSTRM(22),JSIDE(20),P(20,10),IPOPT(20),
     2                 PINFLO(20),EFFSTD(20),ISC(45),IDC(45)
          DIMENSION TRECYC(20),DC(20,10),CRECYC(10),COPT(10),TSUM(10)
     2              ,CSIM(10),RECYC(20)
C
C
          DO 5 K=1,10
5         TSUM(K)=0.
          DO 10 I=2,20
          RECYC(I)=0.
          DO 10 K=1,10
          P(I,K)=0.
10        DC(I,K)=0.
C
C               EVALUATE SYSTEM PERFORMANCE WITH NO RECYCLES
C               MIX RECYCLE FLOWS TOGETHER
C
          CALL SYSTEM(TCS,COPT,RECYC)
          J=JSTRM(17)
          J1=JSTRM(3)
          J2=JSTRM(6)
          J3=JSTRM(20)
          CALL SMIX(J,J1,J2,J3)
          DO 15 I=2,20
15        TRECYC(I)=SMATX(I,J)
C
C               EVALUATE MARGINAL TREATMENT CRITERIA FOR RECYCLE
C               COMPONENTS BY FINDING CHANGE IN CRITERIA FOR IREATING EACH
C               COMPONENT SEPARATELY.
C
          Q1=TRECYC(2)
          Q2=.001*PINFLO(2)
          IF(TRECYC(2).LT.Q2)RETURN
          DO 200 I=2,18
          GO TO (200,20,200,40,50,60,70,80,200,200,200,120,200,140,200,
     2          140,170,190), I
          GO TO 200
C
C               Q
C
20        RECYC(2)=TRECYC(2)
          GO TO 180
C
C               SNBC
C
40        RECYC(2)=Q2
          RECYC(4)=TRECYC(4)*Q1/Q2
          RECYC(3)=RECYC(4)
          RECYC(9)=RECYC(4)
          RECYC(10)=RECYC(4)
          GO TO 180
C
C               SON
C
50        RECYC(2)=Q2
          RECYC(5)=TRECYC(5)*Q1/Q2
          RECYC(9)=RECYC(5)
          RECYC(10)=RECYC(5)
          GO TO 180
```

```
C               SOP
C
60        RECYC(2)=Q2
          RECYC(6)=TRECYC(6)*Q1/Q2
          RECYC(9)=RECYC(6)
          RECYC(10)=RECYC(6)
          GO TO 180
C
C               SFM
C
70        RECYC(2)=Q2
          RECYC(7)=TRECYC(7)*Q1/Q2
          RECYC(10)=RECYC(7)
          GO TO 180
C
C               SBOD
C
80        RECYC(2)=Q2
          RECYC(8)=TRECYC(8)*Q1/Q2
          RECYC(3)=RECYC(8)/1.87
          RECYC(9)=RECYC(8)/1.87
          RECYC(10)=RECYC(8)/1.87
          GO TO 180
C
C               OTHER VSS (NOT SOC, SON, OR SOP)
C
90        RECYC(2)=Q2
          RECYC(9)=(TRECYC(9)-TRECYC(3)-TRECYC(5)-TRECYC(6))*Q1/Q2
          RECYC(10)=RECYC(9)
          GO TO 180
C
C               DNBC
C
120       RECYC(2)=Q2
          RECYC(12)=TRECYC(12)*Q1/Q2
          RECYC(11)=RECYC(12)
          GO TO 180
C
C               OTHER DN (NOT NH3 OR NO3)
C
130       RECYC(2)=Q2
          RECYC(13)=(TRECYC(13)-TRECYC(18)-TRECYC(19))*Q1/Q2
          GO TO 180
C
C               DP AND ALK
C
140       RECYC(2)=Q2
          RECYC(I)=TRECYC(I)*Q1/Q2
          GO TO 180
C
C               DBOD
C
170       RECYC(2)=Q2
          RECYC(17)=TRECYC(17)*Q1/Q2
          RECYC(11)=RECYC(17)/1.87
          GO TO 180
C
C               NH3
C
190       RECYC(2)=Q2
          RECYC(18)=TRECYC(18)*Q1/Q2
          RECYC(13)=RECYC(18)
C
C
180       DO 185 II=2,20
185       IF(RECYC(II).LT.0.)RECYC(II)=0.
          CALL SYSTEM(TCS,CRECYC,RECYC)
```

```
      DO 186 K=1,10
      DC(I,K)=CRECYC(K)-COPT(K)
186   TSUM(K)=TSUM(K)+DC(I,K)
194   DO 195 II=2,20
195   RECYC(II)=0.
200   CONTINUE
C
C
      DO 210 I=1,20
210   RECYC(I)=TRECYC(I)
C
C             PENALTY = MARGINAL CHANGE IN CRITERION / MASS FLOW *
C                                     ADJUSTMENT FACTOR
C             ADJUSTMENT FACTOR = (CRITERION W/ RECYCLE - CRITERION W/O
C                                     RECYCLE) / SUM OF MARGINAL CHANGES
C
      DO 230 K=1,10
      IF(TSUM(K).EQ.0.)GO TO 230
      DEL=(CSIM(K)-COPT(K))/TSUM(K)
      P(2,K)=DC(2,K)*DEL/TRECYC(2)
      DO 220 I=3,20
      IF(TRECYC(I).EQ.0.)GO TO 220
      P(I,K)=DC(I,K)*DEL/(TRECYC(2)*TRECYC(I))
220   CONTINUE
C
C             CORRECT COMPUTED PENALTIES FOR OTHER VSS AND DN
C
      TEMP=TRECYC(9)-TRECYC(3)-TRECYC(5)-TRECYC(6)
      IF(TEMP.LE.0.)GO TO 225
      P(9,K)=P(9,K)*TRECYC(9)/TEMP
225   TEMP=TRECYC(13)-TRECYC(18)- RECYC(19)
      IF(TEMP.LE.0.)GO TO 230
      P(13,K)=P(13,K)*TRECYC(13)/TEMP
230   CONTINUE
      RETURN
      END
C
C
C             STREAM MIXING SUBROUTINE
C
C
      SUBROUTINE SMIX(J,J1,J2,J3)
C
      COMMON SMATX(20,45),DUMMY1(2000),IDUMMY(58),
     2       DUMMY2(27)
      COMMON/PROC/ ID(223),NTPS,NTPU,JSTRM(22),JSIDE(20),P(20,10),
     2             IPOPT(20),DUMMY(40),ISC(45),IDC(45)
C
      SMATX(1,J)=1.
      TEMP1=0.
      DO 10 JT=J1,J2
      IF (JSIDE(JT) .NE. J3) GO TO 10
      TEMP1=TEMP1+SMATX(2,JT+NTPS)
10    CONTINUE
      IF(TEMP1.EQ.0.)GO TO 50
      DO 30 I=3,20
      TEMP2=0.
      DO 20 JT=J1,J2
      IF (JSIDE(JT) .NE. J3) GO TO 20
      TEMP2=TEMP2+SMATX(2,JT+NTPS)*SMATX(I,JT+NTPS)
20    CONTINUE
30    SMATX(I,J)=TEMP2/TEMP1
40    SMATX(2,J)=TEMP1
      RETURN
50    DO 60 I=2,20
60    SMATX(I,J)=0.
      SMATX(2,J)=0.
      RETURN
      END
      SUBROUTINE PREL
C              PRELIMINARY TREATMENT
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     . INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     . ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     . CF,EER,EEP,ALAND
      DO 10 I=2,20
   10 SMATX(I,OS1)=SMATX(I,IS1)
      IPREL=DMATX(1,N)
      X=ALOG(SMATX(2,IS1)*DMATX(16,N))
      IF(IPREL) 30,20,30
   20 CCOST(1)=EXP(2.566569+.619151*X)*1000.
      GO TO 40
   30 CCOST(1)=EXP(3.259716+.619151*X)*1000.
   40 X=ALOG(SMATX(2,IS1))
      OHRS=EXP(6.398716+.230956*X+.164959*X**2-.014601*X**3)
      XMHRS=EXP(5.846098+.206513*X+.068842*X**2+.023824*X**3-
     . .004410*X**4)
      TMSU=EXP(7.235657+.399935*X-.224979*X**2+.110099*X**3-
     . .011026*X**4)
      COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU*WPI)/SMATX(2,1)/3650.
        EER=EXP(2.64866+.532611*X-.034378*X**2+.007274*X**3)
        EER=EER+EXP(.47668+.256486*X-.051504*X**2+.02465*X**3)
        EER=EER+DMATX(1,N)*3.01*EXP(.249*X)
      RETURN
      END

      SUBROUTINE PRSET
C              PRIMARY SEDIMENTATION
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     . INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     . ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     . CF,EER,EEP,ALAND
      HPWK=DMATX(3,N)
      SMATX(2,OS2)=DMATX(1,N)*SMATX(2,IS1)/DMATX(2,N)
      SMATX(2,OS1)=SMATX(2,IS1)-SMATX(2,OS2)
      TEMP1=(1.-DMATX(1,N))*SMATX(2,IS1)/SMATX(2,OS1)
      TEMP2=DMATX(1,N)*SMATX(2,IS1)/SMATX(2,OS2)
      DO 10 I=3,10
      SMATX(I,OS1)=TEMP1*SMATX(I,IS1)
   10 SMATX(I,OS2)=TEMP2*SMATX(I,IS1)
        SMATX(20,OS1)=TEMP1*SMATX(20,IS1)
        SMATX(20,OS2)=TEMP2*SMATX(20,IS1)
      DO 20 I=11,19
      SMATX(I,OS2)=SMATX(I,IS1)
   20 SMATX(I,OS1)=SMATX(I,OS2)
      GPS=-2780.*ALOG(DMATX(1,N))-551.7
      APS=SMATX(2,IS1)*1000./GPS*DMATX(16,N)
      X=ALOG(APS)
      CCOST(1)=EXP(3.716354+.389861*X+.084560*X**2-.004718*X**3)*
     . 1000.
      X=ALOG(APS/DMATX(16,N))
      OHRS=EXP(5.846565+.254813*X+.113703*X**2-.010942*X**3)
      XMHRS=EXP(5.273419+.228329*X+.122646*X**2-.011672*X**3)
      TMSU=EXP(5.669881+.750799*X)
      COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU*WPI)/SMATX(2,1)/3650.
      PGPM=SMATX(2,OS2)*116666.7/HPWK*DMATX(15,N)
      X=ALOG(PGPM)
      CCOST(2)=EXP(2.237330+.207628*X+.026479*X**2)*1000.
      X=ALOG(PGPM/DMATX(15,N))
      OHRS=EXP(4.945155+.419391*X)
      XMHRS=EXP(3.993365+.444966*X)
      TMSU=EXP(4.433129+.642272*X)
      COSTO(2)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU*WPI)/SMATX(2,1)/3650.
      OMATX(1,N)=GPS
      OMATX(2,N)=APS
      OMATX(3,N)=PGPM
      X=ALOG(APS/DMATX(16,N))
      EER=EXP(2,92248+,396798*X+,062424*X**2)
      X=ALOG(SMATX(2,IS1))
      EER=EER+EXP(1,70697+,293587*X+,075918*X**2-
     2            .002995*X**3)
     RETURN
     END

      SUBROUTINE AERFS
C
C             ACTIVATED SLUDGE - FINAL SETTLER
C
      REAL MLSS,MLVSS,MLISS,MLASS,MLRSS
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMAIX(20,50),IP(50),
     2       INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     3       ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     4       CF,EER,EEP,ALAND
C
      IAERF=0
      BODLIM=DMATX(1,N)
      TSSLIM=DMATX(2,N)
      MLVSS=DMATX(3,N)
      RTURN=DMATX(4,N)
      CS   =DMATX(5,N)
      CY   =DMATX(6,N)
      CK   =DMATX(7,N)
      CB1  =DMATX(8,N)
      CKN  =DMATX(9,N)
      AEFF =DMATX(10,N)
      GSS  =DMATX(11,N)
      HEAD =DMATX(12,N)
C
C   COMPUTE INFLUENT CONC. OF BOD AND SOLIDS
      BOD1=SMATX(8,IS1)+SMATX(17,IS1)
      MLASS=0.
      MLRSS=SMATX(4,IS1)*SMATX(9,IS1)/SMATX(3,IS1)
      MLISS=SMATX(7,IS1)
C
C   USE METHOD OF FALSE POSITION TO FIND THE SRT AND BOD2 THAT
C   WILL RESULT IN BODEFF = BODLIM.
C   STEP1 - FIND AN SRT THAT GIVES BODEFF .GT. BODLIM
      SRT=3.
      CB=CB1*SRT**-,415
      BOD2=CS*(1.+CB*SRT)/(SRT*(CY*CK-CB)-1.)
      INDEX=1
      GO TO 25
101   X1=SRT
      Y1=BODEFF-BODLIM
      IF(Y1.LE.0.)GO TO 30
C
C   STEP 2 - FIND AN SRT THAT GIVES BODEFF .LT. BODLIM
      SRT=6.
5     CB=CB1*SRT**-,415
      BOD2=CS*(1.+CB*SRT)/(SRT*(CY*CK-CB)-1.)
      INDEX=2
      GO TO 25
102   X2=SRT
      Y2=BODEFF-BODLIM
      IF(Y2.LE.0.)GO TO 15
      SRT=SRT+3.
      IF(SRT.GT.21.)GO TO 1000
      GO TO 5
C
C   STEP 3 - INTERPOLATE BETWEEN X1 AND X2 TO ESTIMATE A NEW SRT
15    SRT=(X2*Y1-X1*Y2)/(Y1-Y2)
      CB=CB1*SRT**-,415
      BOD2=CS*(1.+CB*SRT)/(SRT*(CY*CK-CB)-1.)
      INDEX=3
      GO TO 25
103   IF(ABS(BODEFF-BODLIM).LE.0.001*BODLIM)GO TO 30
```

```
C
C    STEP 4 - DISCARD OLD POINT THAT IS ON SAME SIDE OF BODLIM AS IS THE
C             CURRENT BODEFF AND RETURN TO STEP 3
      IF(Y1*(BODEFF-BODLIM).LE.0.)GO TO 20
      Y1=Y2
      X1=X2
20    Y2=BODEFF-BODLIM
      X2=SRT
      GO TO 15
C
C    COMPUTE HRT, SETTLER EFFICIENCY, AND BODEFF
25    HRT=SRT/MLVSS*(MLRSS+CY*(BOD1-BOD2)/(1.+CB*SRT)*(1.+.2*CB*SRT))
      XRSS=TSSLIM/(MLVSS+MLISS*SRT/HRT)
      BODEFF=BOD2+.97*.8*XRSS*SRT/HRT*CY*(BOD1-BOD2)/(1.+CB*SRT)
      GO TO (101,102,103), INDEX
C
C    COMPUTE CONC. OF SOLIDS IN AERATOR
30    MLASS=SRT/HRT*CY*(BOD1-BOD2)/(1.+CB*SRT)
      MLRSS=.2*CB*MLASS*SRT+SRT/HRT*MLRSS
      MLISS=SRT/HRT*MLISS
      MLSS=MLVSS+MLISS
C
C    FIND WASTE SLUDGE SOLIDS CONC. AND FLOW RATE
      SMATX(10,OS1)=TSSLIM
      SMATX(10,OS2)=MLSS/RTURN*(1.+RTURN-HRT/SRT)
      SMATX(2,OS2)=SMATX(2,IS1)*(MLSS*(1.+RTURN)-SMATX(10,OS1)-
     2              SMATX(10,OS2)*RTURN)/(SMATX(10,OS2)-SMATX(10,OS1))
      SMATX(2,OS1)=SMATX(2,IS1)-SMATX(2,OS2)
C
C    COMPUTE CONC. OF SOLIDS SPECIES IN OVERFLOW
      SMATX(4,OS1)=XRSS*(.2*CB*MLASS*SRT/2.46+SMATX(4,IS1)*SRT/HRT)
      SMATX(4,OS1)=SMATX(4,OS1)+XRSS*.2*MLASS/2.46
      SMATX(3,OS1)=SMATX(4,OS1)+XRSS*.8*MLASS/2.46
      SMATX(5,OS1)=XRSS*(.12*MLASS+.06*MLRSS)
      SMATX(6,OS1)=XRSS*.025*MLASS
      SMATX(7,OS1)=XRSS*MLISS
      SMATX(8,OS1)=BODEFF-BOD2
      SMATX(9,OS1)=XRSS*MLVSS
      SMATX(20,OS1)=XRSS*MLASS
C
C    COMPUTE CONC. OF SOLID SPECIES IN UNDERFLOW
      R=SMATX(10,OS2)/SMATX(10,OS1)
      DO 40 I=3,9
40    SMATX(I,OS2)=SMATX(I,OS1)*R
      SMATX(20,OS2)=SMATX(20,OS1)*R
C
C    COMPUTE DISSOLVED C, N, P, AND FIXED MATTER
      SMATX(11,OS1)=SMATX(12,IS1)+BOD2/BOD1*(SMATX(11,IS1)-SMATX(12,IS1))
      SMATX(12,OS1)=SMATX(12,IS1)
      SMATX(13,OS1)=SMATX(13,IS1)+SMATX(5,IS1)-SMATX(5,OS1)*SMATX(2,OS1)/
     2SMATX(2,IS1)-SMATX(5,OS2)*SMATX(2,OS2)/SMATX(2,IS1)
      SMATX(14,OS1)=SMATX(14,IS1)+SMATX(6,IS1)-SMATX(6,OS1)*SMATX(2,OS1)/
     2SMATX(2,IS1)-SMATX(6,OS2)*SMATX(2,OS2)/SMATX(2,IS1)
      SMATX(15,OS1)=SMATX(15,IS1)
C
C    CHECK FOR NITRIFICATION (SRT .GE. 5 DAYS)
      IF(SRT.LT.5.)GO TO 50
      IF(SRT*.05*CKN.LE.1.)GO TO 50
      SMATX(18,OS1)=1.*(1./((SRT*.05*CKN)-1.))
      SMATX(19,OS1)=SMATX(13,OS1)-SMATX(18,OS1)
      GO TO 60
50    SMATX(19,OS1)=SMATX(19,IS1)
      SMATX(18,OS1)=SMATX(13,OS1)-SMATX(19,OS1)
C
C    ADJUST ALKALINITY AND DISSOLVED BOD
60    SMATX(16,OS1)=SMATX(16,IS1)-7.14*(SMATX(19,OS1)-SMATX(19,IS1))
      SMATX(17,OS1)=BOD2
      DO 70 I=11,19
70    SMATX(I,OS2)=SMATX(I,OS1)
```

```
C
C   SIZE THE AERATION TANK
      VAER=HRT*SMATX(2,IS1)*DMATX(16,N)
      X=ALOG(VAER*1000,/7,48)
      CCOST(1)=EXP(2.414380+,175682*X+,084742*X**2-,002670*X**3)*1000,
      COSTO(1)=0,
C
C   COMPUTE AIR REQUIREMENTS
      ARCFD=(1,5-1,42*CY)*SMATX(2,IS1)*(BOD1-BOD2)*8,33
      ARCFD=ARCFD+1,42*CB*,8*MLASS*VAER*8,33
      ARCFD=ARCFD+4,6*(SMATX(19,OS1)-SMATX(19,IS1))*SMATX(2,IS1)*8,33
      ARCFD=ARCFD/AEFF/,232/,075
      BSIZE=ARCFD/1440,*DMATX(15,N)
      CFPGL=ARCFD/1,E6/SMATX(2,IS1)
      X=ALOG(BSIZE/1000,)
      CCOST(2)=EXP(4,145454+,633339*X+,031939*X**2-,002419*X**3)*1000,
      X=ALOG(BSIZE/1000,/DMATX(15,N))
      OHRS=EXP(6,900586+,323725*X+,059093*X**2-,004926*X**3)
      XMHRS=EXP(6,169937+,294853*X+,175999*X**2-,040947*X**3+
     2          ,003300*X**4)
      HP=BSIZE/DMATX(15,N)*8,1*144,/(33000,*,8)
      XKW=,8*HP
      XKWPY=XKW*24,*365,
      ECOST=XKWPY*CKWH
      SCOST=EXP(,62138+,482047*X)*1000,
      TMSU=ECOST+SCOST*WPI
      COSTO(2)=((OHRS+XMHRS)*DHR*(1,+PCT)+TMSU)/SMATX(2,1)/3650,
C
C   COMPUTE RETURN SLUDGE PUMPING REQUIREMENTS
      QR=RTURN*SMATX(2,IS1)*DMATX(14,N)
      X=ALOG(QR)
      CCOST(3)=EXP(3,481553+,377485*X+,093349*X**2-,006222*X**3)*1000,
      X=ALOG(QR/DMATX(14,N))
      OHRS=EXP(6,097269+,253066*X-,193659*X**2+,078201*X**3-
     2          ,006680*X**4)
      XMHRS=EXP(5,911541-,013158*X+,076643*X**2)
      IF (QR-1,44) 72,74,74
72    PEFF=,7
      GO TO 80
74    IF (QR-10,08) 76,78,78
76    PEFF=,74
      GO TO 80
78    PEFF=,83
80    YKWPY=QR*1,E6*HEAD/1440,/3690,/PEFF/,9*,7457*24,*365,
      ECOST=YKWPY*CKWH
      SCOST=EXP(5,051743+,301610*X+,197193*X**2-,017962*X**3)
      TMSU=ECOST+SCOST*WPI
      COSTO(3)=((OHRS+XMHRS)*DHR*(1,+PCT)+TMSU)/SMATX(2,1)/3650,
C
C   COMPUTE FINAL SETTLER REQUIREMENTS
      AFS=SMATX(2,OS1)*1000,/GSS*DMATX(13,N)
      AFS2=,04*SMATX(2,IS1)*(1,+RTURN)*MLSS/1000,*(SMATX(10,OS2)/1000,)**,6
      IF(AFS2,GT,AFS)AFS=AFS2
      X=ALOG(AFS)
      CCOST(4)=EXP(3,716354+,389861*X+,084560*X**2-,004718*X**3)*1000,
      X=ALOG(AFS/DMATX(13,N))
      OHRS=EXP(5,846565+,254813*X+,113703*X**2-,010942*X**3)
      XMHRS=EXP(5,273419+,228329*X+,122646*X**2-,011672*X**3)
      TMSU=EXP(5,669881+,750799*X)
      COSTO(4)=((OHRS+XMHRS)*DHR*(1,+PCT)+TMSU*WPI)/SMATX(2,1)/3650,
C
```

```
C    FILL IN OUTPUT MATRIX VALUES
           OMATX(1,N) =BOD1
           OMATX(2,N) =SRT
           OMATX(3,N) =XRSS
           OMATX(4,N) =AFS
           OMATX(5,N) =CK
           OMATX(6,N) =CB
           OMATX(7,N) =VAER
           OMATX(8,N) =VAER
           OMATX(9,N) =MLASS
           OMATX(10,N)=0.
           OMATX(11,N)=MLRSS
           OMATX(12,N)=.2*CB*SRT*MLASS
           OMATX(13,N)=MLISS
           OMATX(14,N)=BOD1-BOD2
           OMATX(15,N)=RTURN
           OMATX(16,N)=CKN
           OMATX(17,N)=ARCFD
           OMATX(18,N)=BSIZE
           OMATX(19,N)=CFPGL
           OMATX(20,N)=QR
C
C    COMPUTE ENERGY REQUIREMENTS
           EER=XKWPY/365.+YKWPY/365.
           EER=EER+EXP(2.8248+.30093*X+.022308*X**2+.0035144*X**3)
           RETURN
 1000      IAERF=1
           RETURN
           END




      SUBROUTINE DIG
C              SINGLE STAGE ANAEROBIC DIGESTION
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     . INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     . ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     . CF,EER,EEP,ALAND
      C1DIG=.28/EXP(.036*(35.-DMATX(2,N)))
      C2DIG=700.*EXP(.10*(35.-DMATX(2,N)))
      DIG12=SMATX(3,IS1)-SMATX(4,IS1)+SMATX(11,IS1)-SMATX(12,IS1)
        TD=DMATX(1,N)
        DIG13=C2DIG/(C1DIG*TD-1.)
20      TEMP1=(DIG12-DIG13)/(SMATX(3,IS1)+SMATX(11,IS1))
      SMATX(2,OS1)=SMATX(2,IS1)
      SMATX(3,OS1)=SMATX(4,IS1)+.75*DIG13
      SMATX(4,OS1)=SMATX(4,IS1)
      SMATX(5,OS1)=(1.-TEMP1)*SMATX(5,IS1)
      SMATX(6,OS1)=(1.-TEMP1)*SMATX(6,IS1)
      SMATX(7,OS1)=SMATX(7,IS1)
      SMATX(8,OS1)=(SMATX(3,OS1)-SMATX(4,OS1))*1.87
      SMATX(9,OS1)=SMATX(3,OS1)*2.38
      SMATX(10,OS1)=SMATX(9,OS1)+SMATX(7,OS1)
      SMATX(11,OS1)=SMATX(12,IS1)+.25*DIG13
      SMATX(12,OS1)=SMATX(12,IS1)
      SMATX(13,OS1)=SMATX(13,IS1)+SMATX(5,IS1)*.65*TEMP1
      SMATX(14,OS1)=SMATX(14,IS1)+TEMP1*SMATX(6,IS1)
      SMATX(15,OS1)=SMATX(15,IS1)
      SMATX(16,OS1)=SMATX(16,IS1)+(SMATX(13,OS1)-SMATX(13,IS1))*3.57
      SMATX(17,OS1)=(SMATX(11,OS1)-SMATX(12,OS1))*1.87
      SMATX(18,OS1)=SMATX(18,IS1)
      SMATX(19,OS1)=SMATX(19,IS1)
        SMATX(20,OS1)=SMATX(20,IS1)*.75*DIG13/(SMATX(3,IS1)-
     2                  SMATX(4,IS1))
      CH4=163.85*(DIG12-DIG13)*SMATX(2,IS1)
      CO2=249.9*(DIG12-DIG13)*SMATX(2,IS1)-CH4
      VDIG=SMATX(2,IS1)*TD*1000./7.48*DMATX(16,N)
      X=ALOG(VDIG)
      IF(VDIG-20.) 22,25,25
```

```
   22 CCOST(1)=EXP(4.594215+.127244*X-.004001*X**2)*1000.
      GO TO 28
   25 CCOST(1)=EXP(7.679634-1.949689*X+.402610*X**2-.018211*X**3)*
     . 1000.
   28 X=ALOG(VDIG/DMATX(16,N))
      IF(VDIG-20.) 30,40,40
   30 OHRS=EXP(6.163803+.166305*X-.012470*X**2)
      XMHRS=EXP(5.726981+.113674*X)
      TMSU=EXP(6.531623+.198417*X+.021660*X**2)
      GO TO 50
   40 OHRS=EXP(9.129250-1.816736*X+.373282*X**2-.017290*X**3)
      XMHRS=EXP(8.566752-1.768137*X+.363173*X**2-.016620*X**3)
      TMSU=EXP(8.702803-1.182711*X+.282691*X**2-.013672*X**3)
   50 COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU*WPI)/SMATX(2,1)/3650.
      OMATX(1,N)=C1DIG
      OMATX(2,N)=C2DIG
      OMATX(3,N)=VDIG
      OMATX(4,N)=CH4
      OMATX(5,N)=CO2
      E1=9.589*VDIG/DMATX(16,N)
      TDIG=1.8*DMATX(2,N)+32.
      CAP=SMATX(2,IS1)*8.33*..E6*(TDIG-60.)
      XX=ALOG(CAP/1000./24.)
      E2=.75*24.*.7457*EXP(2.00069-1.02649*XX+.127492*XX**2)
      E3=.000293*CAP*CF/.75
      E4=VDIG/DMATX(16,N)*62500.*DMATX(3,N)*.000293*CF/.75
      EER=E1+E2+E3+E4
      EEP=CH4*600.*.000293*DMATX(4,N)
     RETURN
     END

     SUBROUTINE VACF
C              VACUUM FILTRATION
     INTEGER OS1,OS2
     COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
    . INP,IO,IS1,IS2,OS1,OS2,N,IAEPF,CCOST(5),COSTO(5),
    . ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
    . CF,EER,EEP,ALAND
     FECL3=DMATX(5,N)
     CAO=DMATX(6,N)
     CFECL=DMATX(7,N)
     CCAO=DMATX(8,N)
     DPOLY=DMATX(9,N)
     CPOLY=DMATX(10,N)
       SAVE1=SMATX(7,IS1)
       SAVE2=SMATX(10,IS1)
     SMATX(7,IS1)=SMATX(7,IS1)+(FECL3+CAO+DPOLY)*SMATX(10,IS1)/2000.
     SMATX(10,IS1)=SMATX(10,IS1)+(FECL3+CAO+DPOLY)*SMATX(10,IS1)/2000.
     SMATX(10,OS2)=DMATX(3,N)
     WP=88./(SMATX(10,IS1)/10000.)**.123
     SMATX(10,OS1)=(100.-WP)*10000.
     SMATX(2,OS1)=(SMATX(2,IS1)*SMATX(10,IS1))/(SMATX(10,OS1)-
    . SMATX(10,OS2))
     SMATX(2,OS2)=SMATX(2,IS1)-SMATX(2,OS1)
     TEMP2=SMATX(10,OS1)/SMATX(10,IS1)
     TEMP3=SMATX(10,OS2)/SMATX(10,IS1)
     DO 10 I=3,9
     SMATX(I,OS1)=TEMP2*SMATX(I,IS1)
  10 SMATX(I,OS2)=TEMP3*SMATX(I,IS1)
       DO 20 I=11,19
       SMATX(I,OS1)=SMATX(I,IS1)
20     SMATX(I,OS2)=SMATX(I,IS1)
       SMATX(20,OS1)=SMATX(20,IS1)*TEMP2
       SMATX(20,OS2)=SMATX(20,IS1)*TEMP3
     SF=SMATX(10,IS1)/10000.
     SC=100.-WP
     FVF=DMATX(1,N)/11.99/(1./SF-1./SC)
     AVF=SMATX(10,IS1)*SMATX(2,IS1)*58.31/FVF/DMATX(2,N)*DMATX(16,N)
     IVACF=1.
     PSDD=SMATX(10,IS1)*SMATX(2,IS1)*8.33
```

```
      X=ALOG(AVF)
      CCOST(1)=EXP(3.288028+.194537*X+.038313*X**2)*1000.
      X=ALOG(PSDD*365./2000.)
      IF(IVACF) 40,30,40
   30 OHRS=EXP(6.069419-.009894*X+.042699*X**2)
      GO TO 50
   40 OHRS=EXP(3.714368+.850848*X-.074615*X**2+.005085*X**3)
   50 XMHRS=EXP(4.306110-.093695*X+.047738*X**2)
      SUPP=EXP(-3.113515+.718466*X)*1000.
      CHEM=PSDD*365./2000.*(FECL3*CFECL+CAO*CCAO+DPOLY*CPOLY)
      COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT)+SUPP*WPI+CHEM)/
     . SMATX(2,1)/3650.
      OMATX(1,N)=WP
      OMATX(2,N)=AVF
      OMATX(3,N)=PSDD
        X=ALOG(AVF/DMATX(16,N))
        EER=EXP(3.21323+.378196*X+.036877*X**2)
        EER=EER+PSDD*(FECL3*.44+CAO*.36+DPOLY*.14)/2000.
        X=ALOG(SMATX(2,IS1)*SMATX(10,IS1)*8.33/2000.)
        EER=EER+EXP(2.3018+.36033*X+.089968*X**2-
     2              .0057516*X**3)
        SMATX(7,IS1)=SAVE1
        SMATX(10,IS1)=SAVE2
      RETURN
      END


      SUBROUTINE THICK
C              GRAVITY THICKENING
      INTEGER OS1,OS2
      DIMENSION SMAT(20)
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     . INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     . ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     . CF,EER,EEP,ALAND
      DO 2 I=1,20
    2 SMAT(I)=0.
      IF(IS2) 7,7,4
    4 DO 6 I=1,20
    6 SMAT(I)=SMATX(I,IS2)
    7 SMATX(10,OS1)=DMATX(2,N)
      SMATX(2,OS1)=DMATX(1,N)*(SMATX(2,IS1)*SMATX(10,IS1)+SMAT(2)*
     . SMAT(10))/SMATX(10,OS1)
      TEMP=DMATX(4,N)/DMATX(3,N)*1000000./8.33
      IF(IS2) 9,8,9
    8 WRT=0.
      GO TO 10
    9 WRT=(SMATX(10,IS1)-TEMP)/(TEMP-SMAT(10))
      SMATX(2,IS2)=WRT*SMATX(2,IS1)
      SMAT(2)=SMATX(2,IS2)
   10 SMATX(2,OS2)=SMATX(2,IS1)+SMAT(2)-SMATX(2,OS1)
      TEMP=SMATX(2,IS1)*SMATX(10,IS1)+SMAT(2)*SMAT(10)
      SMATX(10,OS2)=(TEMP-SMATX(2,OS1)*SMATX(10,OS1))/SMATX(2,OS2)
      TEMP=TEMP/(SMATX(2,IS1)+SMAT(2))
      TEMP1=SMATX(10,OS1)/TEMP
      TEMP2=SMATX(10,OS2)/TEMP
      DO 15 I=3,9
      TEMP3=(SMATX(2,IS1)*SMATX(I,IS1)+SMAT(2)*SMAT(I))/
     . (SMATX(2,IS1)+SMAT(2))
      SMATX(I,OS1)=TEMP1*TEMP3
   15 SMATX(I,OS2)=TEMP2*TEMP3
        TEMP3=(SMATX(2,IS1)*SMATX(20,IS1)+SMAT(2)*SMAT(20))/
     2        (SMATX(2,IS1)+SMAT(2))
        SMATX(20,OS1)=TEMP1*TEMP3
        SMATX(20,OS2)=TEMP2*TEMP3
      DO 20 I=11,19
      SMATX(I,OS1)=(SMATX(I,IS1)*SMATX(2,IS1)+SMAT(I)*SMAT(2))/
     . (SMATX(2,IS1)+SMAT(2))
   20 SMATX(I,OS2)=SMATX(I,OS1)
      ATH1=(SMATX(2,OS2)+SMATX(2,OS1))*1000000./DMATX(3,N)*DMATX(16,N)
      IF(IS2) 40,25,40
   25 ATH2=SMATX(2,IS1)*SMATX(10,IS1)*8.33/DMAIX(4,N)*DMATX(16,N)
      IF(ATH1-ATH2) 30,40,40
   30 ATHM=ATH2
      GO TO 50
   40 ATHM=ATH1
   50 X=ALOG(ATHM/1000.)
      CCOST(1)=EXP(3.725902+.397690*X+.075742*X**2-.001977*X**3-
     . .000296*X**4)*1000.
      X=ALOG(ATHM/1000./DMATX(16,N))
      IF(EXP(X)-1.) 60,70,70
   60 OHRS=350.
      XMHRS=190.
      TMSU=250.
      GO TO 80
   70 OHRS=EXP(5.846565+.254813*X+.113703*X**2-.010942*X**3)
      XMHRS=EXP(5.273419+.228329*X+.122646*X**2-.011672*X**3)
      TMSU=EXP(5.669881+.750799*X)
   80 COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU*WPI)/SMATX(2,1)/3650.
      OMATX(1,N)=ATHM
      OMATX(2,N)=WRT
        X=ALOG(ATHM/DMATX(16,N))
        EER=EXP(5.50543-1.59789*X+.206121*X**2-.005617*X**3)
      RETURN
      END


      SUBROUTINE ELUT
C             ELUTRIATION
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     . INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     . ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     . CF,EER,EEP,ALAND
      SMATX(10,OS1)=DMATX(2,N)
        SAVE=SMATX(2,IS2)
      SMATX(2,IS2)=DMATX(3,N)*SMATX(2,IS1)
      AE1=(SMATX(2,IS1)+SMATX(2,IS2))*1000000./DMATX(4,N)
      AE2=SMATX(2,IS1)*SMATX(10,IS1)*8.33/DMATX(5,N)
        AE2=AE2+(SMATX(2,IS2)*SMATX(10,IS2)*8.33/DMATX(5,N))
      IF(AE1-AE2) 20,20,10
   10 AE=AE1*DMATX(16,N)
      GO TO 30
   20 AE=AE2*DMATX(16,N)
   30 SMATX(2,OS1)=DMATX(1,N)*SMATX(2,IS1)*SMAIX(10,IS1)/SMATX(10,OS1)
      SMATX(2,OS2)=SMATX(2,IS1)+SMATX(2,IS2)-SMATX(2,OS1)
      TEMP=SMATX(2,IS1)*SMATX(10,IS1)+SMATX(2,IS2)*SMATX(10,IS2)
      SMATX(10,OS2)=(TEMP-SMATX(2,OS1)*SMATX(10,OS1))/SMATX(2,OS2)
      TEMP=TEMP/(SMATX(2,IS1)+SMATX(2,IS2))
      TEMP1=SMATX(10,OS1)/TEMP
      TEMP2=SMATX(10,OS2)/TEMP
      DO 40 I=3,9
      TEMP3=(SMATX(2,IS1)*SMATX(I,IS1)+SMATX(2,IS2)*SMATX(I,IS2))/
     . (SMATX(2,IS1)+SMATX(2,IS2))
      SMATX(I,OS1)=TEMP1*TEMP3
   40 SMATX(I,OS2)=TEMP2*TEMP3
        TEMP3=(SMATX(2,IS1)*SMATX(20,IS1)+SMATX(2,IS2)*SMATX(20,IS2))/
     2          (SMATX(2,IS1)+SMATX(2,IS2))
        SMATX(20,OS1)=TEMP1*TEMP3
        SMATX(20,OS2)=TEMP2*TEMP3
      DO 50 I=11,19
      SMATX(I,OS1)=(SMATX(I,IS1)*SMATX(2,IS1)+SMATX(I,IS2)*SMATX(2,IS2))
     . /(SMATX(2,IS1)+SMATX(2,IS2))
   50 SMATX(I,OS2)=SMATX(I,OS1)
      X=ALOG(AE/1000,)
      CCOST(1)=EXP(3,725902+,397690*X+,075742*X**2-,001977*X**3-
     . ,000296*X**4)*1000.
      X=ALOG(AE/1000,/DMATX(16,N))
      IF(EXP(X)-1,) 60,70,70
   60 OHRS=350.
      XMHRS=190.
      TMSU=250.
      GO TO 80
   70 OHRS=EXP(5,846565+,254813*X+,113703*X**2-,010942*X**3)
      XMHRS=EXP(5,273419+,228329*X+,122646*X**2-,011672*X**3)
      TMSU=EXP(5,669881+,750799*X)
   80 COSTO(1)=((OHRS+XMHRS)*DHR*(1,+PCT)+TMSU*WPI)/SMATX(2,1)/3650,
      OMATX(1,N)=AE
        X=ALOG(AE/DMATX(16,N))
        EER=EXP(5,50543-1,59789*X+,206121*X**2-,005617*X**3)
        SMATX(2,IS2)=SAVE
      RETURN
      END


      SUBROUTINE SBEDS
C             SAND DRYING BEDS
      INTEGER OS1,OS2
        COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     . INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     . ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     . CF,EER,EEP,ALAND
      SMATX(2,OS2)=SMATX(2,IS1)
      SMATX(10,OS2)=DMATX(2,N)
      TEMP=SMATX(10,OS2)/SMATX(10,IS1)
      DO 10 I=3,9
   10 SMATX(I,OS2)=TEMP*SMATX(I,IS1)
        SMATX(20,OS2)=TEMP*SMATX(20,IS1)
        DO 20 I=11,19
   20 SMATX(I,OS2)=SMATX(I,IS1)
      SF=SMATX(10,IS1)/10000.
      SC=DMATX(1,N)*100.
      FSB=(29,84*SF-33,3)/SC
      TEMP=SMATX(2,IS1)*SMATX(10,IS1)*249,9
      ASB=TEMP/FSB*DMATX(16,N)
      PSDD=SMATX(10,IS1)*SMATX(2,IS1)*8,33
        SMATX(10,OS1)=DMATX(1,N)*1,E6
        TEMP=SMATX(10,OS1)/SMATX(10,IS1)
        SMATX(2,OS1)=SMATX(2,IS1)/TEMP
        DO 30 I=3,9
30      SMATX(I,OS1)=TEMP*(SMATX(I,IS1)-SMATX(I,OS2))
        SMATX(20,OS1)=TEMP*(SMATX(20,IS1)-SMATX(20,OS2))
        DO 40 I=11,19
40      SMATX(I,OS1)=SMATX(I,IS1)
      X=ALOG(ASB/1000,)
      CCOST(1)=EXP(1,971125+,083841*X+,146751*X**2-,007718*X**3)*
     . 1000.
      X=ALOG(PSDD*365,/2000,)
      OHRS=EXP(6,345052-,476780*X+,101319*X**2)
      XMHRS=EXP(4,290089-,098293*X+,075453*X**2)
      TMSU=EXP(,693148+1,000000*X)
      COSTO(1)=((OHRS+XMHRS)*DHR*(1,+PCT)+TMSU*WPI)/SMATX(2,1)/3650.
      OMATX(1,N)=ASB
        GPM=SMATX(2,IS1)*1,E6/1440.
        EER=(,4355*GPM*SF**1,116)*293,*CF/365.
        ALAND=ASB*2,2E-5
      RETURN
      END
      SUBROUTINE TPFS
C
C             TRICKLING FILTER - FINAL SETTLER
C
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     2       INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTU(5),
     3       ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     4       CF,EER,EEP,ALAND
C
      IAERF=0
C
      BOD5=DMATX(1,N)
      DEGC=DMATX(2,N)
      HQ=DMATX(3,N)
      SAREA=DMATX(4,N)
      TSS7=DMATX(6,N)
      RR=DMATX(7,N)
      GSS=DMATX(8,N)
      YIELD=DMATX(9,N)
      SRATIO=DMATX(10,N)
      TSS5=4.5+.51*BOD5
      IF (TSS5 .GT. DMATX(5,N)) GO TO 200
C
C             COMPUTE REMOVAL EFFICIENCY OF FILTER TO MEET BOD LIMIT
      BOD2=SMATX(8,IS1)+SMATX(17,IS1)
      BOD4=BOD5/SRATIO
      F=BOD4/BOD2
20    IF (F .GT. 1. .OR. F .LT. 0.) GO TO 200
C
C             COMPUTE FILTER AREA AND DEPTH
      BETA=.0245*1.035**(DEGC-20.)
      XN=.91-6.45/SAREA
      A=ALOG((1.+F*RR)/(F+F*RR))/BETA/SAREA
      RHQ=((RR+1.)*HQ)**XN
      DEPTH=RHQ*A
      IF (DEPTH .LE. 30.) GO TO 10
      DEPTH=30.
      RHQ=30./A
      HQ=(1./(RR+1.))*RHQ**(1./XN)
10    FAREA=SMATX(2,IS1)/HQ*43560.
C
C             COMPUTE SLUDGE PRODUCTION
      PDSD=DMATX(9,N)*(BOD2-BOD5)*SMATX(2,IS1)*8.33
C
C             COMPUTE FLOW RATES IN EFFLUENT AND SLUDGE STREAMS
      SMATX(2,OS2)=PDSD/TSS7/8.33
      SMATX(2,OS1)=SMATX(2,IS1)-SMATX(2,OS2)
      SMATX(10,OS1)=4.5+.51*BOD5
      SMATX(10,OS2)=TSS7
C
C             COMPUTE CONC. OF SOLID SPECIES IN EFFLUENT
      R=TSS5*SMATX(2,IS1)/(TSS5*SMATX(2,OS1)+TSS7*SMATX(2,OS2))
      SMATX(4,OS1)=R*SMATX(4,IS1)
      SMATX(8,OS1)=(SMATX(10,OS1)-4.5)*.897
      SMATX(3,OS1)=SMATX(8,OS1)*1.6/2.7+SMATX(4,OS1)
      SMATX(5,OS1)=.1*SMATX(3,OS1)
      SMATX(6,OS1)=.01*SMATX(3,OS1)
      SMATX(7,OS1)=R*SMATX(7,IS1)
      SMATX(9,OS1)=SMATX(10,OS1)-SMATX(7,OS1)
C
C             COMPUTE CONC. OF DISSOLVED SPECIES IN EFFLUENT
      SMATX(17,OS1)=BOD5-SMATX(8,OS1)
      SMATX(11,OS1)=SMATX(12,IS1)+SMATX(17,OS1)*1.6/2.7
      SMATX(12,OS1)=SMATX(12,IS1)
      TEMP=SMATX(2,OS1)/SMATX(2,IS1)
      TEMP=TEMP+SMATX(2,OS2)/SMATX(2,IS1)*SMATX(10,OS2)/SMATX(10,OS1)
      SMATX(13,OS1)=SMATX(5,IS1)+SMATX(13,IS1)-TEMP*SMATX(5,OS1)
      SMATX(14,OS1)=SMATX(6,IS1)+SMATX(14,IS1)-TEMP*SMATX(6,OS1)
      SMATX(15,OS1)=SMATX(15,IS1)
      BODLD=BOD2*SMATX(2,IS1)*8.33/FAREA/DEPTH/1000.
      RN=1.-EXP(-.05*BODLD)
      SMATX(18,OS1)=RN*SMATX(18,IS1)
      SMATX(19,OS1)=(1.-RN)*SMATX(18,IS1)+SMATX(19,IS1)
      SMATX(16,OS1)=SMATX(16,IS1)-10.*(SMATX(18,IS1)-SMATX(18,OS1))
      SMATX(20,OS1)=0.
C
C           COMPUTE CONC. OF SPECIES IN SLUDGE STREAM
      R1=SMATX(10,OS2)/SMATX(10,OS1)
      DO 50 I=3,9
50    SMATX(I,OS2)=R1*SMATX(I,OS1)
      DO 70 I=11,19
70    SMATX(I,OS2)=SMATX(I,OS1)
      SMATX(20,OS2)=0.
C
C           COMPUTE FILTER COSTS
95    VOL=FAREA*DEPTH*DMATX(16,N)
      X=ALOG(VOL/1000.)
      CCOST(1)=EXP(2.924951+.036285*X+.114673*X**2-
     2            .004587*X**3)*1000.
      X=ALOG(SMATX(2,IS1)/HQ*43560./1000.)
      OHRS=EXP(4.536510-.095731*X+.173718*X**2-.010114*X**3)
      XMHRS=EXP(4.312739-.052122*X+.157473*X**2-.010245*X**3)
      TMSU=EXP(5.105946+.465100*X)
      COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU*WPI)/SMATX(2,1)/3650.
C
C           COMPUTE SETTLER COSTS
      AFS=SMATX(2,IS1)*1.E6/GSS*DMATX(15,N)
      X=ALOG(AFS/1000.)
      CCOST(2)=EXP(3.716354+.389861*X+.08456*X**2-.004718*X**3)
     2          *1000.
      X=ALOG(AFS/1000./DMATX(15,N))
      OHRS=EXP(5.846565+.254813*X+.113703*X**2-.010942*X**3)
      XMHRS=EXP(5.273419+.228329*X+.122646*X**2-.011672*X**3)
      TMSU=EXP(5.569881+.750799*X)
      COSTO(2)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU*WPI)/SMATX(2,1)/3650.
C
C           COMPUTE PUMPING REQUIREMENTS
110   QP=1.78*(SMATX(2,IS1)*(1.+RR))**.92
      X=ALOG(QP*DMATX(14,N))
      CCOST(3)=EXP(4.004828+.519499*X+.082262*X**2-.006492*X**3)
     2          *1000.
      X=ALOG(SMATX(2,IS1)*(1.+RR))
      OHRS=EXP(6.097269+.253066*X-.193659*X**2+.078201*X**3
     2          -.00668*X**4)
      XMHRS=EXP(5.911541-.013158*X+.076643*X**2)
      IF (SMATX(2,IS1)-1.44) 120, 130, 130
120   PEFF=.7
      GO TO 160
130   IF (SMATX(2,IS1)-10.08) 140, 150, 150
140   PEFF=.74
```

```
      GO TO 160
150   PEFF=.83
160   YRKW=SMATX(2,IS1)*(1.+RR)*1.E6*(DEPTH+6.)
      YRKW=YRKW/1440./3960./PEFF/.9*.7457*24.*365.
      ECOST=YRKW*CKWH
      SCOST=EXP(5.851743+.30161*X+.197183*X**2-.017962*X**3)
      TMSU=ECOST+SCOST*WPI
      COSTO(3)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU)/SMATX(2,1)/3650.
C
C             FILL IN OUTPUT MATRIX VALUES
      OMATX(1,N)=AFS/1000.
      OMATX(2,N)=VOL/1000.
      OMATX(3,N)=FAREA/43560.
      OMATX(4,N)=DEPTH
C
C             COMPUTE ENERGY AND LAND CONSUMPTION
      EER=YRKW/365.
      X=ALOG(AFS/1000./DMATX(15,N))
      EER=EER+EXP(2.8248+.30093*X+.022308*X**2+.0035144*X**3)
170   ALAND=FAREA/43560.
      RETURN
200   IAERF=1
      RETURN
      END
```

```
      SUBROUTINE CHLOR
C             CHLORINATION - DECHLORINATION
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     . INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     . ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     . CF,EER,EEP,ALAND
      DCL2=DMATX(1,N)
      TCL2=DMATX(2,N)
      CCL2=DMATX(3,N)
      DSO2=DMATX(4,N)
      CSO2=DMATX(5,N)
      BVOL=SMATX(2,IS1)*TCL2/1.44/7.48*1000.*DMATX(16,N)
      X=ALOG(BVOL/1000.)
      CCOST(1)=EXP(2.048061+.521909*X-.002674*X**2+.004159*X**3)*
     . 1000.
      COSTO(1)=0.
      CUSE=SMATX(2,IS1)*DCL2*8.33*365./2000.
      SUSE=SMATX(2,IS1)*DSO2*8.33*365./2000.
      FACTR=CUSE/(CUSE+SUSE)
      X=ALOG(CUSE*2000./365.*DMATX(15,N)+SUSE*2000./365.*DMATX(14,N))
      XCOST=EXP(2.264294-.044271*X+.065029*X**2-.002536*X**3)*1000.
      CCOST(2)=FACTR*XCOST
      X=ALOG(CUSE+SUSE)
      OHRS=EXP(4.538517+.543669*X)
      XMHRS=EXP(3.752071-.224812*X+.158849*X**2-.006064*X**3)
      TMSU=EXP(6.126105+.287016*X)
      OC=FACTR*OHRS
      XC=FACTR*XMHRS
      TMSUC=CUSE*CCL2+FACTR*TMSU
      COSTO(2)=((OC+XC)*DHR*(1.+PCT)+TMSUC)/SMATX(2,1)/3650.
      IF(DSO2) 10,10,20
   10 CCOST(3)=0.
      COSTO(3)=0.
      GO TO 30
   20 CCOST(3)=XCOST-CCOST(2)
      OS=OHRS-OC
      XS=XMHRS-XC
      TMSUS=SUSE*CSO2+(1.-FACTR)*TMSU
      COSTO(3)=((OS+XS)*DHR*(1.+PCT)+TMSUS)/SMATX(2,1)/3650.
   30 DO 40 I=2,20
   40 SMATX(I,OS1)=SMATX(I,IS1)
      OMATX(1,N)=BVOL
      OMATX(2,N)=CUSE
      OMATX(3,N)=SUSE
        PCL2D=DMATX(1,N)*SMATX(2,IS1)*8.33
        X=ALOG(PCL2D)
        EER=1.5*CUSE*2000./365.
        IF(DMATX(4,N).GT.0.)GO TO 50
        EER=EER+EXP(-.071827+.44044*X+.076407*X*-2-.003003*X**3)
        GO TO 60
50      EER=EER+EXP(-.259363+.69229*X+.025652*X**2)
60      EEP=0.
      RETURN
      END


       SUBROUTINE TFLOT
C               FLOTATION THICKENING
       INTEGER OS1,OS2
       DIMENSION Y(12),SMAT(20)
       COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
      . INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
      . ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
      . CF,EEP,EEP,ALAND
       DATA Y/25.,50.,100.,150.,200.,250.,300.,400.,500.,600.,800.,1000./
       DO 5 I=1,20
     5 SMAT(I)=0.
       IF(IS2) 20,20,10
    10 DO 15 I=1,20
    15 SMAT(I)=SMATX(I,IS2)
    20 SMATX(10,OS1)=DMATX(2,N)
       SMATX(2,OS1)=DMATX(1,N)*(SMATX(2,IS1)*SMATX(10,IS1)+
      . SMAT(2)*SMAT(10))/SMATX(10,OS1)
       ATH1=(SMATX(2,IS1)*SMATX(10,IS1)+SMAT(2)*SMAT(10))*
      . 8.33/DMATX(4,N)*168./DMATX(5,N)
       IF(IS2) 30,25,30
    25 ARCY=0.
       GO TO 35
    30 ARCY=.00288*ATH1
       SMATX(2,IS2)=ARCY
    35 SMAT(2)=ARCY
       SMATX(2,OS2)=SMATX(2,IS1)+SMAT(2)-SMATX(2,OS1)
       ATH2=SMATX(2,OS2)*1000000./DMATX(3,N)*168./DMATX(5,N)
       IF(ATH1-ATH2) 40,50,50
    40 ATHM=ATH2*DMATX(16,N)
       GO TO 60
    50 ATHM=ATH1*DMATX(16,N)
    60 TEMP=SMATX(2,IS1)*SMATX(10,IS1)+SMAT(2)*SMAT(10)
       SMATX(10,OS2)=(TEMP-SMATX(2,OS1)*SMATX(10,OS1))/SMATX(2,OS2)
       TEMP=TEMP/(SMATX(2,IS1)+SMAT(2))
       TEMP1=SMATX(10,OS1)/TEMP
       TEMP2=SMATX(10,OS2)/TEMP
       DO 70 I=3,9
       TEMP3=(SMATX(2,IS1)*SMATX(I,IS1)+SMAT(2)*SMAT(I))/
      . (SMATX(2,IS1)+SMAT(2))
       SMATX(I,OS1)=TEMP1*TEMP3
    70 SMATX(I,OS2)=TEMP2*TEMP3
         TEMP3=(SMATX(2,IS1)*SMATX(20,IS1)+SMAT(2)*SMAT(20))/
      2         (SMATX(2,IS1)+SMAT(2))
         SMATX(20,OS1)=TEMP1*TEMP3
         SMATX(20,OS2)=TEMP2*TEMP3
       DO 80 I=11,19
       SMATX(I,OS1)=(SMATX(I,IS1)*SMATX(2,IS1)+SMAT(I)*SMAT(2))
      . /(SMATX(2,IS1)+SMAT(2))
    80 SMATX(I,OS2)=SMATX(I,OS1)
```

```
      ATHM1=ATHM
      XN=0.
      XX=0.
      K=0
      DO 100 I=1,12
      IF(ATHM-Y(I)) 90,90,95
   90 ATHM=Y(I)
      GO TO 110
   95 IF(I-12) 100,96,100
   96 ATHM=Y(12)
  100 CONTINUE
  110 IF(ATHM-25.) 120.120,130
  120 ATHM=25.
      XN=1.
      GO TO 180
  130 IF(ATHM1-1000.) 170,170,140
  140 XN=ATHM1/1000.
      K=XN
      XX=K
      IF((XN-XX)*1000.-500.) 150,150,160
  150 XN=XX+.5
      GO TO 180
  160 XN=XX+1.
      GO TO 180
  170 ATHM=ATHM/2.
      XN=2.
  180 X=ALOG(ATHM)
      CCOST(1)=EXP(1,717538+.453735*X)*1000.*XN
      X=ALOG(ATHM/DMATX(16,N)*XN)
      OHRS=EXP(4,992517-,325053*X+,084026*X**2)
      XMHRS=EXP(4,832373-,336504*X+,083020*X**2)
      HPD=EXP(-1,254959+,852347*X)
        ELEC=HPD*,746*365.*CKWH*DMATX(5,N)/7.
      PWAS=(SMATX(2,IS1)*SMATX(10,IS1)+SMAT(2)*SMAT(10))*8,33
      POLC=PWAS*365./2000.*DMATX(6,N)*DMATX(7,N)
      COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT)+ELEC+POLC)/
     . SMATX(2,1)/3650.
      OMATX(1,N)=ATHM
      OMATX(2,N)=XN
      OMATX(3,N)=ATHM1
        EER=HPD*,746*DMATX(5,N)/7.
      RETURN
      END


      SUBROUTINE MHINC
C             MULTIPLE HEARTH INCINERATION
      INTEGER OS1,OS2
      DIMENSION SFHA(59)
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     . INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     . ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     . CF,EER,EEP,ALAND
      DATA SFHA/85.,98.,112.,125.,126.,140.,145.,166.,187.,193.,208.,
     . 225.,256.,276.,288.,319.,323.,351.,364.,383.,411.,452.,510.,560.,
     . 575.,672.,760.,845.,857.,944.,988.,1041.,1068.,1117.,1128.,1249.,
     . 1260.,1268.,1400.,1410.,1483.,1540.,1580.,1591.,1660.,1675.,
     . 1752.,1849.,1875.,1933.,2060.,2084.,2090.,2275.,2350.,2464.,
     . 2600.,2860.,3120./
      PSDO=SMATX(10,IS1)*SMATX(2,IS1)*8.33
      FHAT=58.31*SMATX(2,IS1)*SMATX(10,IS1)/DMATX(3,N)/DMATX(1,N)*
     . DMATX(16,N)
      XX=FHAT/DMATX(2,N)
      DO 20 I=1,59
      IF(XX-SFHA(I)) 10,10,20
   10 FHA=SFHA(I)
      GO TO 30
   20 CONTINUE
```

```
      FHA=3120.
   30 IF(FHA-200.) 40,40,50
   40 CYT=18.
      GO TO 100
   50 IF(FHA-1700.) 60,60,70
   60 CYT=13.+.024*FHA
      GO TO 100
   70 IF(FHA-2300.) 80,80,90
   80 CYT=.09*(FHA-1100.)
      GO TO 100
   90 CYT=108.
  100 PASH=(SMATX(10,IS1)-SMATX(9,IS1))/SMATX(9,IS1)
      HASH=68.*PASH
      PWAT=(1000000.-SMATX(10,IS1))/SMATX(9,IS1)
      HWSL=1404.3*PWAT
      SAERA=64.03*FHA**.51
      VSPH=SMATX(9,IS1)*SMATX(2,IS1)*58.31/DMATX(3,N)
      HC=1.735*(1.+.374*DMATX(5,N))
      QTRAN=(1.279+HC)*100.*SAERA*DMATX(2,N)/VSPH
      QCOOL=267.*FHA*DMATX(2,N)/VSPH
      QNET=2725.+HASH+HWSL+QCOOL+QTRAN-DMATX(6,N)+246.
      IF(QNET) 105,105,106
  105 QNET=0.
  106 TEMP=SMATX(9,IS1)*SMATX(2,IS1)*8.33*365.
      QNET=QNET*TEMP
      YSBH=8.*CYT/9.+8736.-52.*DMATX(3,N)*7./9.
      YHUH=10.*CYT/9.+52.*CYT*DMATX(4,N)/9.
      QHUP=YHUH*1913.*FHA*DMATX(2,N)
      QSB=YSBH*315.*FHA*DMATX(2,N)
      QTOT=QHUP+QSB+QNET
      IF(DMATX(7,N)-1.) 130,130,140
  130 WFYR=QTOT/15019.
      FCOST=WFYR/7.481*DMATX(8,N)
      GO TO 180
  140 IF(DMATX(7,N)-2.) 150,150,160
  150 WFYR=QTOT/15581.
      FCOST=WFYR/45.8*DMATX(9,N)
      GO TO 180
  160 IF(DMATX(7,N)-3.) 170,170,180
  170 CFDG=QTOT/8967./.0695
      FCOST=0.
  180 TYR=SMATX(10,IS1)*SMATX(2,IS1)*1.52
      WTON=554.24/FHA**.3572
      ECOST=WTON*TYR*CKWH
      DPTON=FCOST/(PSDD*365./2000.)
      X=ALOG(PSDD/24.*DMATX(16,N))
      CCOST(1)=EXP(2.377364+.598986*X)*1000.
      X=ALOG(PSDD*365./2000.*(SMATX(9,IS1)/SMATX(10,IS1)))
      OHRS=EXP(3.402537+1.215130*X-.157203*X**2+.009771*X**3)
      XMHRS=EXP(3.906553+.702471*X-.088337*X**2+.006827*X**3)
      TMSU=EXP(7.864729-.339816*X+.054026*X**2)
      COSTO(1)=((OHRS+XMHRS)*OHR*(1.+PCT)+TMSU*WPI+ECOST+FCOST)/
     * SMATX(2,1)/3650.
      OMATX(1,N)=FHA
      OMATX(2,N)=WFYR
      OMATX(3,N)=PSDD
      OMATX(4,N)=ECOST
      OMATX(5,N)=FCOST
      OMATX(6,N)=CFDG
        EER=ECOST/CKWH/365.+QTOT/365.*.000293*CF
        FS=SMATX(10,IS1)/1.E6
        FV=SMATX(9,IS1)/SMATX(10,IS1)
        WS=(1.-FS)/(FS*FV)
        EX=-((QNET-2725.)-2113.)/1223.
        IF(EX.LT..5)EX=.5
        IF(EX.GT.1.5)EX=1.5
        OPDVS=(800.-60.)*(.505*WS+2.55+2.09*EX)
        IF=DMATX(7,N)
        GO TO (190,200,210),IF
190     F1=4.136
        F2=WFYR
```

```
           GO TO 220
  200      F1=5.63
           F2=WFYR
           GO TO 220
  210      F1=3.151
           F2=CFDG*.0695
  220      QPD=QPDVS*SMATX(9,IS1)*SMATX(2,IS1)*8.33
           QPD=QPD+(800.-60.)/365.*F1*F2
           EEP=QPD*.000293*DMATX(10,N)
         RETURN
         END


      SUBROUTINE RWP
C              RAW WASTEWATER PUMPING
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     . INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     . ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     . CF,EER,EEP,ALAND
      DO 10 I=2,20
   10 SMATX(I,OS1)=SMATX(I,IS1)
      HEAD=DMATX(1,N)
      QP=1.78*SMATX(2,IS1)**.92
      X=ALOG(QP*DMATX(16,N))
      CCOST(1)=EXP(4.004828+.519499*X+.082262*X**2-.006492*X**3)*
     . 1000.
      X=ALOG(SMATX(2,IS1))
      OHRS=EXP(6.097269+.253066*X-.193659*X**2+.078201*X**3-
     . .006680*X**4)
      XMHRS=EXP(5.911541-.013158*X+.076643*X**2)
      IF(SMATX(2,IS1)-1.44) 20,30,30
   20 PEFF=.70
      GO TO 60
   30 IF(SMATX(2,IS1)-10.08) 40,50,50
   40 PEFF=.74
      GO TO 60
   50 PEFF=.83
   60 YRKW=SMATX(2,IS1)*1000000.*HEAD/1440./3960./PEFF/.9*.7457*24.*365.
      ECOST=YRKW*CKWH
      SCOST=EXP(5.851743+.301610*X+.197183*X**2-.017962*X**3)
      TMSU=ECOST+SCOST*WPI
      COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU)/SMATX(2,1)/3650.
      OMATX(1,N)=QP
        EER=YRKW/365.
      RETURN
      END
      SUBROUTINE SHT
C              SLUDGE HOLDING TANKS
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     . INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     . ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     . CF,EER,EEP,ALAND
      DO 10 I=2,20
   10 SMATX(I,OS1)=SMATX(I,IS1)
      VSHT=SMATX(2,IS1)*DMATX(1,N)*1000./7.48*DMATX(16,N)
      X=ALOG(VSHT)
      CCOST(1)=EXP(2.625751+.484180*X+.000613*X**2+.002252*X**3)*
     . 1000.
      V1=SMATX(2,IS1)*DMATX(1,N)*1000./7.48
      X=ALOG(V1)
      OHRS=EXP(5.727345+.000762*X+.098701*X**2-.006786*X**3)
      XMHRS=EXP(4.506628+.214662*X+.071402*X**2-.004681*X**3)
      TMSU=EXP(5.479939+.299282*X+.106008*X**2-.008658*X**3)
      COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU*WPI)/SMATX(2,1)/3650.
      OMATX(1,N)=VSHT
        EER=0.
      RETURN
      END
      SUBROUTINE CENT
C             CENTRIFUGATION
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     . INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     . ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     . CF,EER,EEP,ALAND
        DIMENSION CPDATA(4,2)
        DATA CPDATA/.73,.8,.43,.41,1.6,1.48,.81,.74/
      HPWK=DMATX(3,N)
      XCEN=1.
      POLY=DMATX(5,N)
      CPOLY=DMATX(6,N)
      GPMN=DMATX(7,N)
      CNMIN=DMATX(8,N)
        SAVE1=SMATX(7,IS1)
        SAVE2=SMATX(10,IS1)
      SMATX(7,IS1)=SMATX(7,IS1)+POLY*SMATX(10,IS1)/2000.
      SMATX(10,IS1)=SMATX(10,IS1)+POLY*SMATX(10,IS1)/2000.
      DSOL=SMATX(10,IS1)*SMATX(2,IS1)*8.33*365./2000.
      SMATX(10,OS2)=((1.-DMATX(1,N))/(1.-DMATX(1,N)*SMATX(10,IS1)/
     . DMATX(2,N)))*SMATX(10,IS1)
      TEMP1=DMATX(2,N)/SMATX(10,IS1)
      TEMP2=SMATX(10,OS2)/SMATX(10,IS1)
      SMATX(10,OS1)=DMATX(2,N)
      SMATX(2,OS1)=(SMATX(10,IS1)-SMATX(10,OS2))*SMATX(2,IS1)/
     . (SMATX(10,OS1)-SMATX(10,OS2))
      SMATX(2,OS2)=SMATX(2,IS1)-SMATX(2,OS1)
      DO 11 I=3,9
      SMATX(I,OS1)=TEMP1*SMATX(I,IS1)
   11 SMATX(I,OS2)=TEMP2*SMATX(I,IS1)
        SMATX(20,OS1)=TEMP1*SMATX(20,IS1)
        SMATX(20,OS2)=TEMP2*SMATX(20,IS1)
      DO 21 I=11,19
      SMATX(I,OS1)=SMATX(I,IS1)
   21 SMATX(I,OS2)=SMATX(I,IS1)
      CN=CNMIN
      CGPM=SMATX(2,IS1)*116666.7/HPWK*DMATX(16,N)/CN
      GPMM=SMATX(2,IS1)*1000000./1440.
      CSIZE=.275*GPMN
      IF(CGPM-CSIZE) 8,8,2
    2 CSIZE=.350*GPMN
      IF(CGPM-CSIZE) 12,12,4
    4 CSIZE=.590*GPMN
      IF(CGPM-CSIZE) 16,16,6
    6 CSIZE=GPMN
      NCN=CGPM/CSIZE
      CN=NCN+1
      GO TO 20
    8 IF(GPMM-CSIZE*(CN-1.)) 24,24,10
   10 CN=CN+1.
      GO TO 8
   12 IF(GPMM-CSIZE*(CN-1.)) 26,26,14
   14 CN=CN+1.
      GO TO 12
   16 IF(GPMM-CSIZE*(CN-1.)) 28,28,18
   18 CN=CN+1.
      GO TO 16
   20 IF(GPMM-CSIZE*(CN-1.)) 30,30,22
   22 CN=CN+1.
```

```
      GO TO 20
   24 CCOST(1)=78500.*(1.-.044*(CN-2.))*CN
      GO TO 32
   26 CCOST(1)=98000.*(1.-.044*(CN-2.))*CN
      GO TO 32
   28 CCOST(1)=140000.*(1.-.044*(CN-2.))*CN
      GO TO 32
   30 CCOST(1)=160000.*(1.-.044*(CN-2.))*CN
   32 AFC=RI*(1.+RI)**10./((1.+RI)**10.-1.)
      ACOST(1)=CCOST(1)*AFC/SMATX(2,1)/3650.
      X=ALOG(DSOL)
      IF(XCEN) 40,34,40
   34 OHRS=EXP(7.621517-.476977*X+.071516*X**2)
      GO TO 50
   40 OHRS=EXP(7.264153-.466246*X+.069552*X**2)
   50 XMHRS=EXP(5.997115-.493809*X+.070892*X**2)
      SUPP=EXP(-2.822519+.700948*X)*1000.
      CHEM=DSOL*POLY*CPOLY
      COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT)+SUPP*WPI+CHEM)/
     . SMATX(2,1)/3650.
      OMATX(1,N)=CGPM
      OMATX(2,N)=DSOL
      OMATX(3,N)=AFC
      OMATX(4,N)=CSIZE
      OMATX(5,N)=CN
        SMATX(7,IS1)=SAVE1
        SMATX(10,IS1)=SAVE2
        EER=GPMM*.7457*24.
      RETURN
      END



        SUBROUTINE AEROB
C
C                 AEROBIC DIGESTION
C
        INTEGER OS1,OS2
        COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     2         INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     3         ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     4         CF,EER,EEP,ALAND
C
        SRT=DMATX(3,N)
        DEGC=DMATX(4,N)
        DTA=DMATX(5,N)
        CB1 =DMATX(6,N)
        CY  =DMATX(7,N)
        TSS1=DMATX(8,N)
        TSS2=DMATX(9,N)
        CKN =DMATX(10,N)
        AEFF=DMATX(11,N)
C
C   COMPUTE INFLUENT BIOMASS, REFRACTORIES,  AND BOD
        XASSIN=SMATX(20,IS1)
        XRSSIN=SMATX(4,IS1)/SMATX(3,IS1)*SMATX(9,IS1)-.2*XASSIN
        SIN=SMATX(8,IS1)+SMATX(17,IS1)-.97*.8*XASSIN
C
C
C   FIND EFFLUENT SOLIDS CONC.
        CB=CB1*(SRT+DTA)**-.415*(1.05)**(DEGC-20.)
        XASS=(XASSIN+CY*SIN)/(1.+.8*CB*DTA)
        XRSS=XRSSIN+.2*CB*XASS*DTA
        TSS=SMATX(7,IS1)+XASS+XRSS
C
```

```
C   FIND FLOW RATES IN OUTPUT STREAMS
        IF(TSS2.EQ.0.)GO TO 60
        IF(TSS2.GT.TSS)GO TO 60
        SMATX(10,OS1)=TSS1
        SMATX(10,OS2)=TSS2
        SMATX(2,OS1)=SMATX(2,IS1)*(TSS-TSS2)/(TSS1-TSS2)
        SMATX(2,OS2)=SMATX(2,IS1)-SMATX(2,OS1)
        RSS=TSS1/TSS
        GO TO 70
60      SMATX(10,OS1)=TSS
        SMATX(10,OS2)=0.
        SMATX(2,OS1)=SMATX(2,IS1)
        SMATX(2,OS2)=0.
        RSS=1.
C
C   DETERMINE EFFLUENT SOLIDS CONC.
70      SMATX(4,OS1)=RSS*(SMATX(4,IS1)+.4*(XRSS-XRSSIN)-.4*.2*(XASSIN-XASS))
        SMATX(3,OS1)=SMATX(4,OS1)+RSS*.4*.8*XASS
        SMATX(5,OS1)=RSS*(.06*XRSS+.12*XASS)
        SMATX(6,OS1)=RSS*(.025*XASS)
        SMATX(7,OS1)=RSS*SMATX(7,IS1)
        SMATX(8,OS1)=RSS*.97*.8*XASS
        SMATX(9,OS1)=RSS*(XASS+XRSS)
        SMATX(20,OS1)=RSS*XASS
        R=SMATX(10,OS2)/SMATX(10,OS1)
        DO 80 I=3,9
80      SMATX(I,OS2)=SMATX(I,OS1)*R
        SMATX(20,OS2)=SMATX(20,OS1)*R
C
C   DETERMINE EFFLUENT CONC. OF SOLUBLE C, N, P, AND FIXED MATTER
        SMATX(12,OS1)=SMATX(12,IS1)
        SMATX(11,OS1)=SMATX(12,OS1)
        SMATX(13,OS1)=SMATX(13,IS1)+SMATX(5,IS1)-SMATX(5,OS1)*SMATX(2,OS1)/
     2  SMATX(2,IS1)-SMATX(5,OS2)*SMATX(2,OS2)/SMATX(2,IS1)
        SMATX(14,OS1)=SMATX(14,IS1)+SMATX(6,IS1)-SMATX(6,OS1)*SMATX(2,OS1)/
     2  SMATX(2,IS1)-SMATX(6,OS2)*SMATX(2,OS2)/SMATX(2,IS1)
        SMATX(15,OS1)=SMATX(15,IS1)
C
C   CHECK FOR NITRIFICATION
        IF(SRT+DTA.LT.5.) GO TO 90
        IF(CKN.EQ.0.) GO TO 90
        CKN=CKN*1.05**(DEGC-20.)
        SMATX(18,OS1)=1./((SRT+DTA)*.05*CKN-1.)
        SMATX(19,OS1)=SMATX(13,OS1)-SMATX(18,OS1)
        GO TO 100
90      SMATX(19,OS1)=SMATX(19,IS1)
        SMATX(18,OS1)=SMATX(13,OS1)-SMATX(19,OS1)
C
C   ADJUST ALKALINITY AND SOLUBLE BOD
100     SMATX(16,OS1)=SMATX(16,IS1)-7.14*(SMATX(19,OS1)-SMATX(19,IS1))
        IF(SMATX(16,OS1).LT.20.)SMATX(16,OS1)=20.
        SMATX(17,OS1)=1.
        IF(SMATX(2,OS2).EQ.0.) GO TO 120
        DO 110 I=11,19
110     SMATX(I,OS2)=SMATX(I,OS1)
        GO TO 140
120     DO 130 I=11,19
130     SMATX(1,OS2)=0.
C
C   SIZE DIGESTOR
140     VAER=DTA*SMATX(2,IS1)*DMATX(16,N)*1000./7.48
        X=ALOG(VAER)
        CCOST(1)=EXP(2.414380+.175682*X+.084742*X**2-.002670*X**3)*1.E3
        COSTO(1)=0.
C
```

```
C   COMPUTE AIR REQUIREMENTS
      ACFM=(1.5-1.42*CY)*SMATX(2,IS1)*SIN*8.33
      CB=CB1*(1.05**(DEGC-20.))*(SRT+DTA)**-.415
      ACFM=ACFM+1.42*CB*.8*XASS*VAER*1.E3*7.48*8.33/1.E6
      ACFM=ACFM+4.6*(SMATX(19,OS1)-SMATX(19,IS1))*SMATX(2,IS1)*8.33
      ACFM=ACFM/AEFF/.232/.075/1440.*DMATX(15,N)
      IF(20.*VAER*DMATX(15,N).GT.ACFM)ACFM=20.*VAER*DMATX(15,N)
      X=ALOG(ACFM/1000.)
      CCOST(2)=EXP(4.145454+.633339*X+.031939*X**2-.002419*X**3)*1.E3
      XX=ACFM/1000./DMATX(15,N)
      X=ALOG(XX)
      IF(XX.GE.1.)GO TO 150
      OHRS=850.
      XMHRS=350.
      GO TO 160
150   OHRS=EXP(6.900586+.323725*X+.059093*X**2-.004926*X**3)
      XMHRS=EXP(6.169937+.294853*X+.17599*X**2-.040947*X**3+.0033*X**4)
160   HP=ACFM/DMATX(15,N)*8.1*144./(33000.*.8)
      XKW=.8*HP
      XKWPY=XKW*24.*365.
      ECOST=XKWPY*CKWH
      SCOST=1000.*EXP(.62138+.482047*X)
      TMSU=ECOST+SCOST*WPI
      COSTO(2)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU)/SMATX(2,1)/3650.
C
C   ASSIGN VALUES TO OUTPUT MATRIX
      OMATX(1,N)=VAER
      OMATX(2,N)=ACFM
      OMATX(3,N)=0.
      OMATX(4,N)=0.
C
C   COMPUTE ENERGY REQUIREMENTS
      EER=XKWPY/365.
      RETURN
      END



C
C               LAND DISPOSAL SUBROUTINE
C
      SUBROUTINE LANDD
C
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     2        INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     3        ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     4        CF,EER,EEP,ALAND
      DIMENSION CAPAC(6),TRUCK(6).OPER(6),TMPG(6)
      DATA CAPAC/1200.,2500.,5500.,10.,15.,30./
      DATA TRUCK/25000.,42000.,55000.,25000.,42000.,50000./
      DATA OPER/.2,.25,.3,.2,.25,.3/
      DATA TMPG/4.5,4.5,3.5,4.5,4.5,3.5/
C
      WHPY=DMATX(1,N)
      DIST=DMATX(2,N)
      YRSL=DMATX(3,N)
      FCOST=DMATX(4,N)
      SP=DMATX(7,N)
      TNMAX=DMATX(8,N)
      ECFT=DMATX(15,N)
      AFCTR=RI*(1.+RI)**YRSL/((1.+RI)**YRSL-1.)
C
```

```
C               COMPUTE HAULING COSTS
C
         SLV=0.
         JSTYPE=0
         WS=(SMATX(10,IS1)+SMATX(15,IS1))*SMAIX(2,IS1)*8.33
         WW=SMATX(2,IS1)*8.33E6-WS
         IF(WS/(WS+WW).GE.0.15) JSTYPE=1
         IF(JSTYPE.EQ.1)GO TO 10
         ASV=SMATX(2,IS1)*365.E6
         J1=0
         GO TO 20
10       ASV=(WS+WW)*365./55./27.
         J1=3
20       CT=1.E20
         ARS=25.
         IF(DIST.GT.20.)ARS=(25.*20./DIST)+(35.*(DIST-20.)/DIST)
         AHPT=(2.*DIST/ARS)+.75
         TPTPY=WHPY/AHPT
         DO 30 KTYPE=1,3
         TPY=ASV/CAPAC(J1+KTYPE)
         NT=TPY/TPTPY*ECFT+.9999999
         ATM=TPY*2.*DIST
         FUEL=ATM/TMPG(J1+KTYPE)
         TMHPY=AHPT*TPY*1.1
         CC=NT*TRUCK(J1+KTYPE)*WPI*118.2/150.2
         CA=CC*.85*AFCTR+.15*CC*RI
         CO=FUEL*FCOST+ATM*OPER(J1+KTYPE)*WPI*117.5/170.3
         CO=CO+TMHPY*DHR*(1.+PCT)
         IF(CA+CO.GE.CT)GO TO 30
         CT=CA+CO
         CCOST(2)=CC
         ACOST(2)=CA
         COSTO(2)=CO
         EER=FUEL
         OMATX(1,N)=TPY/NT
         OMATX(2,N)=TPY
         OMATX(3,N)=NT
30       CONTINUE
         EER=EER*140000.*.000293*CF/365.
C
C           ADD ON FACILITY COSTS
         IF(JSTYPE.EQ.1)GO TO 25
         Q=ASV/1.E6
         C1=20015.*Q**.32
         C2=19950.*Q**.40
         C3=  936.*Q**.22
         C4=  900.*Q**.3
         GO TO 28
25       Q=ASV/1.E3
         IF(Q.LT.15.)GO TO 26
         C1=13849.*Q**.32
         GO TO 27
26       C1=32387.
27       C2=17700.*Q**.40
         C3=  936.*Q**.22
         C4=  900.*Q**.3
28       CCOST(2)=CCOST(2)+C1
         ACOST(2)=(ACOST(2)+C1*AF)/SMATX(2,1)/3650.
         TMSU=C2*CKWH+C3*WPI
         COSTO(2)=(COSTO(2)+(C4*DHR*(1.+PCT)+TMSU))
         COSTO(2)=COSTO(2)/SMATX(2,1)/3650.
         EER=EER+C2/365.
C
```

```
C              COMPUTE STORAGE COSTS
C
      TONS=WS*365./2000.
      IF(DMATX(6,N).GT.0.)GO TO 60
      ALAND=SMATX(2,IS1)*(SMATX(5,IS1)+SMATX(13,IS1))*3040./TNMAX
      IF(JSTYPE.EQ.1)GO TO 50
      SLV=SP*365.*SMATX(2,IS1)*1.E6/7.48/1.E3*DMATX(16,N)
      IF(SLV.LE.0.)GO TO 40
      X=ALOG(SLV)
      CCOST(1)=EXP(.375449+.394996*X+.014726*X**2)*1000.
40    IF(TONS.LE.0.)GO TO 50
      X=ALOG(TONS)
      OHRS=EXP(6.567594-.971759*X+.095689*X**2)*SP
      XMHRS=EXP(-2.087393+2.395831*X-.340388*X**2+
     2          .017499*X**3)*SP
      COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT))/SMATX(2,1)/3650.
C
C              COMPUTE LAND AND APPLICATION COSTS
C
50    CCOST(3)=ALAND*DMATX(9,N)
      COSTO(3)=(ALAND*DMATX(5,N)*RI+TONS*DMATX(10,N))/SMATX(2,1)/3650.
      IF(JSTYPE.EQ.1)GO TO 55
      EER=EER+180.*SMATX(2,IS1)*293.*CF
      GO TO 70
55    EER=EER+71.43*ASV/1000.*293.*CF/365.
      GO TO 70
C
C              COMPUTE LANDFILL COSTS
C
60    WTPD=TONS/365.+WW/2000.
      ALAND=3.75E-3*WTPD*365.
      CCOST(3)=ALAND*DMATX(5,N)+1.E4*(WTPD**.74)*1.506/2.4
      COSTO(3)=9480.*(WTPD**.625)*1.192/1.7/SMATX(2,1)/3650.
      EER=EER+18.*ASV/1000.*293.*CF/365.
C
C              FILL IN OUTPUT DATA
C
70    OMATX(4,N)=SLV
      OMATX(5,N)=TONS
      OMATX(6,N)=ALAND
      OMATX(7,N)=ALAND*DMATX(5,N)*RI
      IF(DMATX(6,N).GT.0.)OMATX(7,N)=0.
      OMATX(8,N)=ALAND*DMATX(5,N)
      OMATX(9,N)=AFCTR
      RETURN
      END
```

```
      SUBROUTINE LIME
C             LIME ADDITION TO SLUDGE
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     . INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     . ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     . CF,EER,EEP,ALAND
      DLIME=DMATX(1,N)
      CLIME=DMATX(2,N)
      DTON=(SMATX(10,IS1)+SMATX(15,IS1))*SMATX(2,IS1)*8.33/2000.
      PPDL=DLIME*DTON*DMATX(16,N)
      DO 10 I=2,6
   10 SMATX(I,OS1)=SMATX(I,IS1)
      SMATX(7,OS1)=SMATX(7,IS1)+PPDL/8.33/SMATX(2,IS1)
      SMATX(8,OS1)=SMATX(8,IS1)
      SMATX(9,OS1)=SMATX(9,IS1)
      SMATX(10,OS1)=SMATX(10,IS1)+PPDL/8.33/SMATX(2,IS1)
        SMATX(20,OS1)=0.
      DC 20 I=11,19
   20 SMATX(I,OS1)=SMATX(I,IS1)
      X=ALOG(PPDL)
      CCOST(1)=EXP(-1.800487+.670797*X)*1000.
      X=ALOG(PPDL/DMATX(16,N))
      OHRS=0.
      XMHRS=EXP(6.060054+.197073*X)
      CHEM=PPDL*365.*CLIME/2000.
      COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT)+CHEM)/
     . SMATX(2,1)/3650.
      OMATX(1,N)=PPDL
      OMATX(2,N)=DTON
        EER=EXP(2.077+.001*1.32*DLIME+.7*ALOG(DTON*2000.))/
     2       365.+.36*PPDL
      RETURN
      END



      SUBROUTINE RBC
C            ROTATING BIOLOGICAL CONTACTOR - FINAL SETTLER
      INTEGER OS1,OS2
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IF(50),
     . INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     . ACOST(5), DHR,PCT,*PI,CCI,RI,AF,RATIO ,CK*H,
     . CF,EER,EEP,ALAND
      BOD=DMATX(1,N)
      XNSTG=DMATX(2,N)
      DEGC=DMATX(3,N)
      QPABI=DMATX(4,N)
      QPANI=DMATX(5,N)
      GSS=DMATX(6,N)
      BODN=DMATX(7,N)
      TSS=DMATX(8,N)
      CPDI=DMATX(9,N)
        YIELD=DMATX(10,N)
      QPAB=DMATX(4,N)*1.04**(DMATX(3,N)-20.)
      QPAN=DMATX(5,N)*1.04**(DMATX(3,N)-20.)
      RBOD=DMATX(1,N)/(SMATX(17,IS1)+SMATX(8,IS1))
      TEMP1=ALOG(RBOD)/DMATX(2,N)
      TEMP2=1./EXP(TEMP1)-1.
      APSTG=SMATX(2,IS1)*1000000.*TEMP2/QPAB
        NTRN=APSTG*DMATX(16,N)/1.E5
        NTRN=NTRN+1
        NSHFT=NTRN*XNSTG
        XNTRN=NTRN
        XSHFT=NSHFT
        AREA=XSHFT*1.E5
        POSD=YIELD*(SMATX(8,IS1)+SMATX(17,IS1)-BOD)*SMATX(2,IS1)*8.33
      TEMP3=1./(1.+QPAB*APSTG/SMATX(2,IS1)/1000000.)
      RBOD=DMATX(7,N)/(SMATX(17,IS1)+SMATX(8,IS1))
      FNSTG=ALOG(RBOD)/ALOG(TEMP3)
      RNSTG=XNSTG-FNSTG
      RNH3=(1./(1.+QPAN*APSTG/SMATX(2,IS1)/1000000.))**RNSTG
      SMATX(18,OS1)=SMATX(18,IS1)*RNH3
      SMATX(2,OS2)=POSD/DMATX(8,N)/10000./8.33
      SMATX(2,OS1)=SMATX(2,IS1)-SMATX(2,OS2)
      SMATX(10,OS1)=4.5+.51*DMATX(1,N)
      SMATX(10,OS2)=DMATX(8,N)*10000.
      SMATX(8,OS1)=(SMATX(10,OS1)-4.5)*.897
      SMATX(17,OS1)=DMATX(1,N)-SMATX(8,OS1)
      SMATX(19,OS1)=SMATX(18,IS1)-SMATX(18,OS1)
      URSS=SMATX(2,IS1)/(SMATX(2,OS1)+SMATX(2,OS2)*SMATX(10,OS2)/
     . SMATX(10,OS1))
      SMATX(4,OS1)=URSS*SMATX(4,IS1)
      SMATX(3,OS1)=SMATX(8,OS1)*1.6/2.7+SMATX(4,OS1)
      SMATX(5,OS1)=.1*SMATX(3,OS1)
      SMATX(6,OS1)=.01*SMATX(3,OS1)
      SMATX(7,OS1)=URSS*SMATX(7,IS1)
      SMATX(9,OS1)=SMATX(10,OS1)-SMATX(7,OS1)
      SMATX(11,OS1)=SMATX(12,IS1)+SMATX(17,OS1)*1.6/2.7
      SMATX(12,OS1)=SMATX(12,IS1)
        TEMP=SMATX(2,OS1)/SMATX(2,IS1)
        TEMP=TEMP+SMATX(2,OS2)/SMATX(2,IS1)*SMATX(10,OS2)/SMATX(10,OS1)
        SMATX(13,OS1)=SMATX(5,IS1)+SMATX(13,IS1)-TEMP*SMATX(5,OS1)
        SMATX(14,OS1)=SMATX(6,IS1)+SMATX(14,IS1)-TEMP*SMATX(6,OS1)
      SMATX(15,OS1)=SMATX(15,IS1)
      SMATX(16,OS1)=SMATX(16,IS1)-10.*(SMATX(18,IS1)-SMATX(18,OS1))
        SMATX(20,OS1)=0.
        SMATX(20,OS2)=0.
      TEMP4=SMATX(10,OS2)/SMATX(10,OS1)
      DO 60 J=3,9
   60 SMATX(J,OS2)=TEMP4*SMATX(J,OS1)
      DO 70 J=11,19
   70 SMATX(J,OS2)=SMATX(J,OS1)
      AFS=SMATX(2,OS1)*1000000./DMATX(6,N)*DMATX(15,N)
      PREM=(SMATX(18,IS1)-SMATX(18,OS1))*100./SMATX(18,IS1)
      QPAI=SMATX(2,IS1)*1000000./APSTG/XNSTG
      IF(NSHFT-20) 80,80,90
   80 CCOST(1)=(28500.+45.*DMATX(9,N))*NSHFT*1.506/2.1215
      GO TO 100
   90 CCOST(1)=(23000.+45.*DMATX(9,N))*NSHFT*1.506/2.1215
  100 X=ALOG(AREA/1000./DMATX(16,N))
      OHRS=EXP(1.323670+.524215*X+.023076*X**2)
      XMHRS=EXP(-.124185+.840104*X+.007757*X**2)
      COSTL=(OHRS+XMHRS)*DHR*(1.+PCT)
      COSTM=(CCOST(1)-45.*DMATX(9,N)*NSHFT*1.506/2.1215)*.02
      COSTE=NSHFT*5.*.746*24.*365.*CKWH
      TMSU=COSTM+COSTE
      COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU)/SMATX(2,1)/3650.
      X=ALOG(AFS/1000.)
      CCOST(2)=EXP(3.716354+.389861*X+.084560*X**2-.004718*X**3)*
       1000.
      X=ALOG(AFS/1000./DMATX(15,N))
      OHRS=EXP(5.846565+.254813*X+.113703*X**2-.010942*X**3)
      XMHRS=EXP(5.273419+.228329*X+.122646*X**2-.011672*X**3)
      TMSU=EXP(5.669881+.750799*X)
      COSTO(2)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU*WPI)/SMATX(2,1)/3650.
      OMATX(1,N)=QPAB
      OMATX(2,N)=QPAN
      OMATX(3,N)=APSTG
      OMATX(4,N)=AREA
      OMATX(5,N)=FNSTG
      OMATX(6,N)=RNSTG
      OMATX(7,N)=RATIO
      OMATX(8,N)=PREM
      OMATX(9,N)=QPAI
      OMATX(10,N)=AFS
      OMATX(11,N)=PDSD
      OMATX(12,N)=URSS
      OMATX(13,N)=XNTHN
      OMATX(14,N)=XSHFT
      OMATX(15,N)=COSTM
      OMATX(16,N)=COSTE
      OMATX(17,N)=COSTL
        EER=COSTE/365./CKWH
        EER=EER+EXP(2.8248+.30093*X+.022308*X**2+
     2              .0035144*X**3)
      RETURN
      END
```

```
C
      SUBROUTINE PSASFS
C
C     PRIMARY SEDIMENTATION, ACTIVATED SLUDGE, WAS RETURNED TO PRIMARY
C     CLARIFIER.
C
      INTEGER OS1,OS2,OS11,OS12,OS21,OS22,OS1SAV,OS2SAV
      COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
     2       INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
     2       ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
     3       CF,EER,EEP,ALAND
      DIMENSION TRECYC(20),CTEMP(5),TEMPO(5),ATEMP(5)
C
C             SAVE STREAM AND PROCESS ID NUMBERS
C
      NITER=1
      IS1SAV=IS1
      OS1SAV=OS1
      OS2SAV=OS2
      NSAVE=N
      N1=DMATX(1,N)
      N2=DMATX(2,N)
      EPS=.001
      NITMAX=20
      IS11=OS2+1
      OS11=OS2+2
      OS12=OS2
      OS21=OS1
      OS22=OS2+3
      DO 10 I=2,20
      SMATX(I,OS22)=0.
10    TRECYC(I)=0.
C
C             MIX STREAM IS1SAV WITH OS22
C
20    TEMP1=SMATX(2,OS22)+SMATX(2,IS1SAV)
      DO 30 I=3,20
      TEMP2=SMATX(2,OS22)*SMATX(I,OS22)
      TEMP2=TEMP2+SMATX(2,IS1SAV)*SMATX(I,IS1SAV)
30    SMATX(I,IS11)=TEMP2/TEMP1
      SMATX(2,IS11)=TEMP1
C
C             EVALUATE PROCESS PERFORMANCES
C
      N=N1
      IS1=IS11
      OS1=OS11
      OS2=OS12
      DO 40 I=1,5
      CCOST(I)=0.
      COSTO(I)=0.
40    ACOST(I)=0.
      CALL PRSET
      DO 45 I=1,5
      CTEMP(I)=CCOST(I)
      TEMPO(I)=COSTO(I)
45    ATEMP(I)=ACOST(I)
      EERTMP=EER
      N=N2
      IS1=OS11
      OS1=OS21
      OS2=OS22
      DO 50 I=1,5
      CCOST(I)=0.
      ACOST(I)=0.
50    COSTO(I)=0.
      CALL AERFS
      IF(IAERF.GT.0)GO TO 1000
```

```
        DO 55 I=1,5
        CCOST(I)=CCOST(I)+CTEMP(I)
        COSTO(I)=COSTO(I)+TEMPO(I)
 55     ACOST(I)=ACOST(I)+ATEMP(I)
        EER=EER+EERTMP
 C
 C              COMPARE RECYCLE STREAM OS22 *ITH TRECYC
 C
        DO 60 I=2,20
        IF(ABS(SMATX(I,OS22)-TRECYC(I))-SMATX(I,OS22)*EPS)60,60,70
 60     CONTINUE
        GO TO 90
 C
 C              CONVERGENCE NOT ATTAINED. INCREMENT ITERATION COUNT.
 C              SAVE STREAM OS22 IN TRECYC. REPEAT ANOTHER ITERATION.
 C
 70     NITER=NITER+1
        IF(NITER.GT.NITMAX)GO TO 1000
        DO 80 I=2,20
 80     TRECYC(I)=SMATX(I,OS22)
        GO TO 20
 C
 C              CONVERGENCE ATTAINED.
 C
 90     N=NSAVE
        DO 100 I=1,20
 100    OMATX(I,N)=OMATX(I,N2)
        RETURN
 C
 C              ITERATION LIMIT EXCEEDED OR MLASS CANNOT BE ATTAINED.
 C
 1000   IAERF=1
        GO TO 90
        END


        SUBROUTINE HEAT
 C
 C              HEAT TREATMENT SUBROUTINE
 C
        INTEGER OS1,OS2
        COMMON SMATX(20,45),DMATX(20,50),OMATX(20,50),IP(50),
      2        INP,IO,IS1,IS2,OS1,OS2,N,IAERF,CCOST(5),COSTO(5),
      3        ACOST(5),DHR,PCT,WPI,CCI,RI,AF,RATIO,CKWH,
      4        CF,EER,EEP,ALAND
 C
        I1=DMATX(1,N)
        I2=DMATX(2,N)
        IDIG=DMATX(3,N)
        TEMP=DMATX(4,N)
 C
 C      FIND FRACTION OF SLUDGE FROM PRIMARY TREATMENT
        IF(IDIG.GT.0)GO TO 30
        IF(I1.EQ.0) GO TO 10
        IF(I2.EQ.0) GO TO 20
        FPRI=1.-SMATX(2,I2)*SMATX(10,I2)/SMATX(2,I1)/SMATX(10,I1)
        GO TO 30
 10     FPRI=0.
        GO TO 30
 20     FPRI=1.
 C
 C      COMPUTE EFFLUENT STREAM CHARACTERISTICS
 30     AS=1,3255-,00457*TEMP
        AP=1,8112-,00596*TEMP
        AD=1,9698-,00709*TEMP
        BS=1,5855-,00657*TEMP
        BP=1,8455-,00657*TEMP
        BD=1,9855-,00757*TEMP
        GND=,00163*TEMP+,1755
        GD=,00163*TEMP+,0755
      ALPHA=(1-IDIG)*(FPRI*AP+(1.-FPRI)*AS)+IDIG*AD
      BETA=(1-IDIG)*(FPRI*BP+(1.-FPRI)*BS)+IDIG*BD
      GAMMA=(1-IDIG)*GND+IDIG*GD
      SMATX(2,OS1)=SMATX(2,IS1)
      SMATX(3,OS1)=SMATX(3,IS1)*BETA
      SMATX(4,OS1)=SMATX(3,OS1)*SMATX(4,IS1)/SMATX(3,IS1)
      SMATX(5,OS1)=SMATX(5,IS1)*BETA
      SMATX(6,OS1)=SMATX(6,IS1)*BETA
      SMATX(7,OS1)=SMATX(7,IS1)
      SMATX(8,OS1)=SMATX(8,IS1)*ALPHA
      SMATX(9,OS1)=SMATX(9,IS1)*BETA
      SMATX(10,OS1)=SMATX(7,OS1)+SMATX(9,OS1)
      SMATX(11,OS1)=SMATX(11,IS1)+(SMATX(3,IS1)-SMATX(3,OS1))
      SMATX(12,OS1)=SMATX(11,OS1)*(1.-GAMMA)
      SMATX(13,OS1)=SMATX(13,IS1)+SMATX(5,IS1)*(1.-BETA)
      SMATX(14,OS1)=SMATX(14,IS1)+SMATX(6,IS1)*(1.-BETA)
      SMATX(15,OS1)=SMATX(15,IS1)
      SMATX(16,OS1)=SMATX(16,IS1)+(SMATX(13,OS1)-SMATX(13,IS1))*3.57
      SMATX(17,OS1)=SMATX(17,IS1)+SMATX(8,IS1)*SMATX(3,IS1)/
     2              (SMATX(3,IS1)-SMATX(4,IS1))*(1.-ALPHA)*GAMMA
      SMATX(18,OS1)=SMATX(13,OS1)*(.00274*TEMP-.307)
      SMATX(19,OS1)=SMATX(19,IS1)
      SMATX(20,OS1)=BETA*SMATX(20,IS1)
C
C     EVALUATE COST AND ENERGY REQUIREMENTS
      GPM=SMATX(2,IS1)*116666.7/DMATX(5,N)*DMATX(16,N)
      X=ALOG(GPM)
      CCOST(1)=EXP(5.9096-.050119*X+.073395*X**2)*1000.*.60873
      OHRS=EXP(8.4281-.084636*X+.05961*X**2)
      OHRS=OHRS*DMATX(5,N)*52./8000.
      XMHRS=.25*OHRS
      TMSU=EXP(8.8497-.13093*X+.073644*X**2)*.6643*WPI
      XKWPY=.007*GPM/DMATX(16,N)*60.*DMATX(5,N)*52.
      ECOST=XKWPY*CKWH
      QTOT=(TEMP-20.)*.25*15./.75*GPM/DMATX(16,N)*60.*DMATX(5,N)*52.
      HPD=DMATX(5,N)/DMATX(6,N)
      IF(HPD.LT.8.)FK=2000.
      IF(HPD.LT.16.)FK=1500.
      IF(HPD.LT.24.)FK=1000.
      IF(HPD.GE.24.)FK=0.
      SPY=DMATX(6,N)*52.
      QTOT=QTOT+(12.*2000.+FK*(SPY-12.))*GPM/DMATX(16,N)*60.
      FCOST=FUEL*DMATX(7,N)/1.E6
      TMSU=TMSU+ECOST+FCOST
      COSTO(1)=((OHRS+XMHRS)*DHR*(1.+PCT)+TMSU)/SMATX(2,1)/3650.
      EER=XKWPY/365.+QTOT/365.*.000293*CF
C
C     FILL IN VALUES OF OUTPUT MATRIX
      OMATX(1,N)=GPM
      OMATX(2,N)=ALPHA
      OMATX(3,N)=BETA
      OMATX(4,N)=QTOT/1.E6
      RETURN
      END
```